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Integrated Pest Management on Rangeland

State of the Art in the Sagebrush Ecosystem

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ABSTRACT

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Several sagebrush communities represent optimum levels of negative development plant productivity for certain peculiar sites, and therefore should be managed for their preservation. Other sagebrush communities may be profitably modified to favor forage species that are more palatable to domestic livestock. Modification techniques can range from subtle (i.e., grazing strategies) to tracematic (i.e., brush removal and revegetation), and an associated spectrum of management tactics are described. Interrelationships between and problems associated with management of forage resources, management of weeds, and management of insects (including grasshoppers, black grass bugs, and beneficial insects) are discussed. Economical analyses, the role of modeling as a management tool, and impacts of management tactics on wildlife and non-target species also are discussed.

KEYWORDS: IPM, pest management, range, range-land, sagebrush, brush control, weed control, bladegrass bugs, grasshopper control, rangeland modeling, range revegetation

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Cover photograph: Part of the sagebrush region of Western North America--an extensive stand of Wyoming big sagebrush (A. tridentata ssp. wyomingensis) in central Utah.

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Integrated Pest Management on Rangeland

State of the Art in
the Sagebrush Ecosystem

Jerome A. Onsager
Editor

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PREFACE

This publication provides the text of 12 papers that were presented by invitation at a symposium entitled "Integrated Pest Management on Rangeland: State-of-the-Art in the Sagebrush Ecosystem." The objectives were to stimulate dialogue between research and extension personnel in range-related disciplines, to identify opportunities for interdisciplinary approaches to management of pests or pest complexes on rangeland, and to provide a basis for prioritization of interdisciplinary research breeds for IPM on rangeland.

The symposium was sponsored by Western Regional Research Project No. W-161, Integrated Pest Management.

Topics for discussion and candidate speakers were selected by the following representatives of the Range Subcommittee of W-161: K. H. Asay, Logan, UT; R. A. Evans, Reno, NV; K. L. Johnson, Logan, UT; J. B. Knight, Reno, NV; J. A. Onsager, Bozeman, MT, Chairman; G. L. Piper, Pullman, WA; and B. F. Roche, Jr., Pullman, WA. The symposium was held on March 27-28, 1984, at the University of Nevada, Reno, NV.

My thanks are extended to all who contributed to the symposium: To the Western Regional IPM Coordinator, Gary A. McIntyre, Colorado State University, Fort Collins, CO; to the W-161 Rangeland Subcommittee; to J. B. Knight, University of Nevada, Reno, NV, for providing local arrangements; to the speakers and other participants of the symposium; and to Vera Christie, Rangeland Insect Laboratory, Bozeman, MT for preparing camera-ready copies of manuscripts.

Jerome A. Onsager, Editor.

SAGEBRUSH TYPES AS ECOLOGICAL INDICATORS TO
INTEGRATED PEST MANAGEMENT (IPM) IN THE SAGEBRUSH
ECOSYSTEM OF WESTERN NORTH AMERICA

Kendall L. Johnson

ABSTRACT

Integrated Pest Management (IPM) is a structured approach to ecosystem management based on ecological analysis of vegetation sites. As applied in the sagebrush ecosystem of western North America, broad suitability classes of the species are developed as a continuum based on site, habitat and distribution characteristics. Of the 21 sagebrush taxa deemed important to an IPM analysis in the sagebrush region, 11 are of negative utility, 6 are of problematic worth, and 4 are of positive utility. These designations are a first approximation only for each species on each site will have its own successional patterns.

INTRODUCTION

Integrated Pest Management (IPM) is a structured approach to ecosystem management based on a general understanding of the ecology, uses and interactions of the plant species within it. An IPM program attempts to identify the several negative effects, actual or potential, on an ecosystem of animal, plant, insect, and pathogen pests. These form the bases of an integrated approach toward the amelioration of those effects consistent with the ecological capabilities of the ecosystem. Because an ecosystem is normally much too broad a focus for management activities, IPM is usually addressed to smaller areas of similar soils and vegetation, often known as range sites. In short, IPM is a program of applied ecology.

As applied in the sagebrush ecosystem of western North America, IPM must center on sagebrush itself for two main reasons. First, sagebrush is widely regarded as the principal pest, and second, sagebrush is a strong indicator of ecological conditions of the site vital to the successful application of IPM. Hence the land manager is required to assess the ecological characteristics of the sagebrush site, to evaluate that profile within a set of management objectives, to decide whether treatment is warranted, and if so, to develop a treatment prescription.

This paper attempts to develop an overall appraisal of the major sagebrush species and types as the basis for an initial segregation into broad suitability classes for the application of IPM. In this sense it represents but an introduction and an initial approach to the classification. Actual application of an IPM analysis in the field will depend on a much more detailed consideration of site, species, condition and productive potential.

SAGEWORT, WORMWOOD, AND SAGEBRUSH

The large and well-established genus *Artemisia* L. contains over 200 species distributed throughout the temperate regions of the northern hemisphere. The species include herbaceous, suffrutescent, and woody growth forms of wide ecological amplitude, but occur primarily in the arid steppe areas of Eurasia, North America, and Africa. In the Pacific and Rocky Mountain West of North America, there are at least 30-35 well-defined taxa, although some authorities have recognized many more (McArthur 1979, Harrington 1964, Hitchcock and Cronquist 1973).

A few of the North American herbaceous forms are annual or biennial, and sometimes are weeds; a much larger number are perennial plants. Some are of circumboreal distribution extending far south in the mountains (e.g., boreal wormwood [*A. norvegica*] and northern wormwood [*A. campestris*]). A wide ecological amplitude is evident among herbaceous *Artemisias*, including Rocky Mountain sagewort (*A. scopulorum*) of alpine regions, those of widespread cordilleran distribution like Michaux sagewort (*A. michauxiana*), and those equally widespread over plains, foothills, and lower mountains such as Louisiana sagewort (*A. ludoviciana*). While the herbaceous species can be locally abundant, and are frequently important components of their plant associations, they seldom attain such dominance over large areas as to characterize the landscape. There are few North American sagewort ecosystems, and those are typically of small size (Gregory 1982), but there are many sagebrush ecosystems, typically of wide extent. It is the woody members of *Artemisia* which form a major vegetation region (Figure 1), and are by far the most widely distributed zonal vegetation of the interior West (Blaisdell et al. 1982).

Based on similarities in floral characteristics, the species of *Artemisia* have been grouped into four sections; *Artemisia*, *Dracunculus*, *Seriphidium*, and *Tridentatae* (McArthur and Plummer 1978). The *Tridentatae*, a natural group of closely related



Figure 1.--Part of the sagebrush region of western North America--an extensive stand of Wyoming big sagebrush (*A. tridentata* ssp. *wyomingensis*) in central Utah.

woody species endemic to western North America, are distinguished by campanulate heads of perfect disc flowers, lacking ray flowers entirely. Further, while woody plants occur in all the other sections of Artemisia, the Tridentatae are entirely woody shrubs confined to North America. The 19 taxa in Tridentatae (11 species, 6 subspecies, 2 forms) recognized by Beetle (1960) and Beetle and Young (1965) include those species customarily regarded as sagebrushes. The archtypical big sagebrush (A. tridentata) is the central species of the group in both presence and distribution.

Other woody species important to the western sagebrush ecosystem are three suffrutescent to shrubby members of the section Dracunculus, distinguished by pistillate ray flowers and staminate disc flowers, and one member of the section Artemisia, with pistillate ray flowers and perfect disc flowers. Although other woody Artemisias occur in the region (e.g., coaltown sagebrush [A. argilosa]), or on its periphery (e.g., coastal sagebrush [A. californica]), or have been introduced (e.g., oldman wormwood [A. abrotanum]), they are not regarded as ecologically or geographically significant to the western sagebrush ecosystem of the interior West. The several species and subspecies of Artemisia deemed to occupy important places in that ecosystem are listed in Table 1.

Distribution and Dominance

Many of the sagebrushes, especially members of the A. tridentata complex, occur as major and often single dominants of large continuous stands extending over miles of medium elevation rangeland. They also occur in complex edaphic and climatic patterns

Table 1.--Taxa of Artemisia characteristic of the western sagebrush ecosystem in the interior west

Section Species	Taxonomic characters
<u>Artemisia</u>	
<u>A. frigida</u>	Perfect disc flowers Pistillate ray flowers Suffrutescent
<u>Dracunculus</u>	
<u>A. filifolia</u>	Staminate disc flowers
<u>A. pedatifida</u>	Pistillate ray flowers
<u>A. spinescens</u>	Suffrutescent to woody
<u>Tridentatae</u>	
<u>A. arbuscula</u> ssp. <u>arbuscula</u>	
<u>A. arbuscula</u> ssp. <u>thermopola</u>	
<u>A. bigelovii</u>	
<u>A. cana</u> ssp. <u>cana</u>	
<u>A. cana</u> ssp. <u>bolanderi</u>	
<u>A. cana</u> ssp. <u>viscidula</u>	
<u>A. longiloba</u>	
<u>A. nova</u>	Perfect disc flowers
<u>A. pygmaea</u>	Ray flowers lacking ^{1/}
<u>A. rigida</u>	Woody
<u>A. rothrockii</u>	
<u>A. tridentata</u> ssp. <u>tridentata</u>	
<u>A. tridentata</u> ssp. <u>vaseyana</u>	
<u>A. tridentata</u> ssp. <u>spiciformis</u> ^{2/}	
<u>A. tridentata</u> ssp. <u>wyomingensis</u>	
<u>A. tripartita</u> ssp. <u>tripartita</u>	
<u>A. tripartita</u> ssp. <u>rupicola</u>	

^{1/} A single exception, A. bigelovii, has a pistillate ray flower or two.

^{2/} Nomenclature according to Goodrich et al. (1985); previously ssp. spiciformis had been included in the A. rothrockii distribution outside the Sierra Nevada (Beetle 1960).

with other vegetation types, such as salt desert shrubs at lower elevations and foothill trees in higher zones. In addition, they often form important parts of other vegetative communities, such as the mountain brush type. The varied ecological expressions of the sagebrushes make estimates of their total distribution both difficult and relative, depending on the criteria employed to determine presence or dominance. These factors are evident in the following prominent estimates of total sagebrush distribution in western North America:

USDA Forest Service (1936)	95 million acres
Beetle (1960)	270 million acres
Branson et al. (1967)	143 million acres

Depending on the estimate criteria, each of these or similar assessments may be valid. For the present purpose, the difference between estimates of overall distribution matters but little, because application of IPM can proceed within any acceptable definition of a sagebrush ecosystem or community.

The bounds of the western sagebrush ecosystem are generally defined as the area of occurrence of the Tridentatae species, extending from southern British Columbia and Alberta through all or most of the eleven western United States into Baja California (Figure 2). A. spinescens and A. pedatifida of Dracunculus occur within the range of Tridentatae, but A. filifolia extends the sagebrush distribution through the Plains and Trans-Pecos regions of Texas and on into northern Chihuahua (Correll and Johnston 1970). A. frigida, with the most cosmopolitan distribution of any North American Artemisia, occurs over most of the map area of Figure 2 and beyond it into western Canada and Alaska as part of a circumboreal distribution. Within this enormous area may be found the varying occurrences of sagebrush as communities, stands, or dominants important to application of IPM.

Although there is general agreement among western plant ecologists on the present distributional limits of Artemisia, there is disagreement on the density and local distribution of the sagebrushes in pre-European settlement times. Historically as well as presently, it is likely that the sagebrushes often formed homogeneous stands ranging from a few acres to several square miles. They also interacted with each other and with other shrubby species in complex mosaics, or were simply parts of diverse vegetative communities. It is also likely that relative density within any expression of sagebrush was a function of several environmental factors, especially fire. Thus a mosaic of relative sagebrush densities probably resulted, within which the new factor of livestock grazing introduced by European settlement was exerted (Tisdale and Hironaka 1981).

Because most of the sagebrushes exhibit a strong increaser response to grazing pressure, some observers have maintained that an extensive change of grassland to shrubland has occurred as a result of abusive land use (Cottam and Stewart 1940, Cottam 1961, Hull and Hull 1974, Stoddard et al.

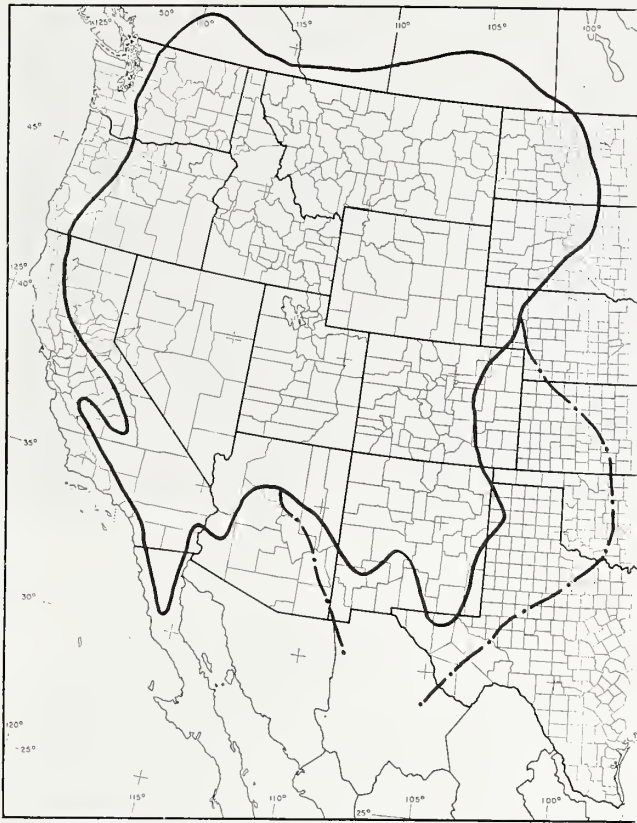


Figure 2.--Distribution of sagebrush in western North America (after McArthur 1983). The solid line encloses the distribution of subgenus *Tridentatae*; the broken line -- • -- delimits the approximate extension of *A. filifolia* beyond the *Tridentatae* region (after Great Plains Flora Association 1977).

1975). Others have held that the distribution is ecologically stable and that boundaries remain largely the same as those of pre-European settlement (Vale 1975, Hironaka 1979, Johnson 1979, Tisdale et al. 1969).

No definitive information on changes in sagebrush density within or without distributional limits is available. Over the region as a whole, there appears to be little doubt that some grazing-induced increase of shrubs and reduction of native herbaceous perennials have occurred. The supposition forms one of the principal bases for the application of IPM within the western sagebrush ecosystem (West 1979).

The Sagebrushes as Environmental Indicators

Because the distribution of sagebrush species is related to climate (precipitation and temperature) and soil development, occurrence has an indicator value of site potential, and therefore of basic management strategy. For example, all of the dwarf sagebrush species occur on soils that are either shallow, have a shallow restrictive layer, or are highly impermeable (Hironaka et al. 1983). Such ecological conditions indicate that control or improvement efforts may not be useful or may even

be counterproductive, resulting in a lower site condition. In such event, no application of IPM involving sagebrush control should be contemplated.

Conversely, sagebrush types occurring in less restrictive environments, and found to be in low ecological condition, may indicate a control strategy wherein proper choices of treatment technique and species for reseeding will improve chances of success, resulting in a more productive site in higher condition. For example, several xeric species of sagebrush occur on relatively shallower and drier soils at lower elevations in the region. Winward (1983) points out that relevant considerations for IPM on such sites derive from their xeric nature, which makes them more readily abused, slower to recover, and treatment-sensitive than more mesic types. The use of fire may not be feasible due to low levels of fine fuels. Therefore, control efforts must be applied either mechanically or chemically, and must be followed by proper seeding of species adapted to xeric growing conditions. Post-treatment management must be both intensive and sensitive, to derive full utility from the improvements and to maintain a higher site condition.

Another characteristic of the sagebrushes pertinent to IPM development is the concept of intrinsic value. Several of the taxa are valuable browse plants for wildlife or livestock, especially on winter and spring ranges. Notable among these are Bigelow sagebrush (*A. bigelovii*) and budsage (*A. spinescens*). Indeed, nearly all of the sagebrushes have at least some ecotypes of seasonal grazing value. Some species of sagebrush, especially the *A. tridentata* complex, may be important in maintenance of upland bird populations, particularly sage grouse. Still other species, such as sand sagebrush (*A. filifolia*), may be useful as soil stabilizers. Hence the first derivative of an IPM assessment must include the latent values of the sagebrush present. Shrubs that are useful and desirable, and of reasonable density, do not invite control efforts.

Thus the sagebrushes can help indicate those habitats where control measures should not be applied for either ecological or latent value reasons, or, conversely, those habitats where improvement efforts should be implemented and the reclamation approaches most likely to succeed. As noted by many authors (Plummer 1977, Winward and Tisdale 1977, McArthur et al. 1979, Winward 1980), management strategies must be keyed not only to the taxa but within a taxon by locations. The design of IPM programs must reflect this dictum precisely.

AN ECOLOGICAL BASIS FOR IPM

Consideration of the ecological and latent value profiles of the sagebrush species yields an arrangement of the taxa along a loose continuum of occurrence and distribution. Although in many ways the continuum is circular, it can be thought to originate with species of very limited occurrence and disjunct distribution, proceed through taxa adapted to harsh sites of low productive potential

and limited distribution, continue through those more widely distributed on sites of medium productive potential, and terminate in taxa of very wide ecological amplitude, high site density, frequent occurrence, and panregional distribution. For an IPM assessment, the continuum can be divided into three fairly clear classes of productive potential and three major, but not coincident, groups of distribution. These constructs represent a first approximation only, for each species on each site will have its own successional pattern, use history, and management profile, which together will outline the appropriate strategy.

Sites of Low Productive Potential

Sagebrush taxa adapted to growth-limiting conditions often represent the climax vegetation of their sites. Consideration of IPM involving control of such taxa must boil down to a simple question: Why? For example, pygmy sagebrush (A. pygmaea) is a dwarf, cushionlike shrub inhabiting dry, calcareous soils in the southeastern part of the Great Basin and the Colorado Plateau. It has virtually no value as browse, yet adaptation to the harsh growing conditions of its sites makes it a valuable ground cover, rendering control efforts questionable.

Similar relations are found with several other dwarf sagebrush taxa (see Table 2). Birdfoot sagebrush (A. pedatifida), which forms small, isolated stands on dry, shallow plateau soils of northern Wyoming (Figure 3), is valueless as browse but valuable as a site stabilizer. On shallow, rocky ridgetops and knolls of central and southern Wyoming may be found Wyoming threetip sagebrush (A. tripartita ssp. rupicola), an inconspicuous, spreading shrub adapted to adverse growing conditions. Stiff (scabland) sagebrush (A. rigida) is adapted to the scoured and infertile 'scablands' of the Northwest, clearly the climax vegetation of a very harsh, unproductive range



Figure 3.--Typical small, isolated stand of birdfoot sagebrush (A. pedatifida) in northern Wyoming, an example of sagebrush taxa adapted to sites of low productive potential.

site. Also in the Northwest, Bolander silver sagebrush (A. cana ssp. bolanderi) is found in internally-drained basins of clayey, alkaline soils so impermeable as to develop standing water in the spring. Frequently, very few other plants occur in its association. Early (alkali) sagebrush (A. longiloba), characteristic of heavy, impermeable soils derived from alkaline shales, initiates growth earlier than other sagebrushes and as a consequence has been valuable as spring lambing browse as well as a site stabilizer.

Although early sagebrush, Bolander silver sagebrush, and sometimes stiff sagebrush have browse value, it is the adaptation of the low-potential species which make them inherently valuable. Environmental conditions make associated herbaceous flora sparse or wanting in all of the areas dominated by these taxa. Establishment of introduced species through seeding is very chancy and difficult. Because the existing flora is

Table 2.--Taxa of Artemisia adapted to sites of low productive potential

Taxa	Growth form	Distribution	Habitat	Latent Value
Birdfoot sagebrush <u>A. pedatifida</u>	Dwarf subshrub to .5 ft	WY n. to MT; 6-8,000 ft	Dry soils of plateaus, ridges and hills	No known browse use
Bolander silver sagebrush <u>A. cana</u> ssp. <u>bolanderi</u>	Low, thickly branched, round shrub to 2 ft	OR s. to W. NV and N. CA; 5,500 ft	Impermeable, alkaline soils of internally drained basins	Moderate browse use
Early (alkali) sagebrush <u>A. longiloba</u>	Low, spreading shrub to 1.5 ft; layers	MT to CO w. to OR and NV; 6-8,000 ft	Heavy soils on alkaline shales; sometimes lighter limy soils	Spring lambing range
Pygmy sagebrush <u>A. pygmaea</u>	Dwarf, cushionlike shrub to .8 ft	W. UT, E. NV, N. AZ; 4-6,000 ft	Dry, calcareous soils of desert areas	No known browse use
Stiff (scabland) sagebrush <u>A. rigida</u>	Low shrub with thick, rigid branches to 1.5 ft	C. WA s. to OR and ID; 3-6,000 ft	Rocky, shallow soils or scablands	Variable browse use by location
Wyoming threetip sagebrush <u>A. tripartita</u> ssp. <u>rupicola</u>	Dwarf shrub with decumbent branches to .5 ft; sprouts and layers	SE. to C. WY; 7-9,000 ft	Dry, rocky knolls and ridges	No known browse use

generally superior to any treatment derivative, the best management strategy usually is to leave the native shrubs in peace, and to control present uses of the types so as to maintain or improve their ecological condition. On sagebrush sites of low productive potential, IPM has equally low and even negative potential.

Sites of Medium Productive Potential

Several sagebrush taxa inhabit sites of moderate productive potential, giving rise to species having significant browse or soil stabilization values (see Table 3). Most are of major occurrence in the sagebrush region, and a few play central roles in its ecological and management economy. Because less-limiting environmental conditions allow the reduction of native shrubs and establishment of introduced species, if planned and conducted correctly, there appears to be a reasonable opportunity to improve productivity. A balanced IPM appraisal, however, must also include the qualities of ecological site adaptation and intrinsic utility. Consideration of IPM involving these taxa is best conducted under a simple but very important qualification: maybe.

For example, sand sagebrush (*A. filifolia*) is an excellent indicator of sandy soils and often has browse value, depending somewhat on availability of other forage. Probably the most widespread shrub on dunes and other deep sands through the southeastern quadrant of the sagebrush region, the shrub has definite value as a soil stabilizer, but is sometimes regarded as a problem in local areas

(Scifres 1980). Therefore the plant may be profitably controlled in some situations, but overall its value as a soil stabilizer will likely be the dominant characteristic in the appraisal.

Budsage (*A. spinescens*) and Bigelow sagebrush (*A. bigelovii*) are both very drought-resistant shrubs adapted to xeric (often salty in the case of budsage) growing conditions. They also have high palatability and nutrient value to most forms of livestock and wildlife, especially in late winter and early spring (Holmgren and Hutchings 1972). All such factors will prove important in an IPM analysis, leading in nearly every case to a management strategy which leaves the native shrubs in place.

Plains silver sagebrush (*A. cana* ssp. *cana*) occurs widely but sparsely over the northern Great Plains, but is important throughout its range as a winter browse shrub for both livestock and big game (Figure 4). The shrub layers readily and when disturbed can sprout profusely. These physiological characters, together with its winter forage value and its generally sparse distribution, indicate no action to reduce populations is needed where its densities are reasonable. Where layering of the shrub has overtaken the associated herbaceous flora, its density can be reduced through properly applied herbicidal treatments (Beetle and Johnson 1982). The role of plains silver sagebrush in IPM must always involve such a site-by-site appraisal of conditions.

Table 3.--Taxa of *Artemisia* adapted to sites of medium productive potential

Taxa	Growth form	Distribution	Habitat	Latent Value
Bigelow sagebrush <i>A. bigelovii</i>	Small, spreading shrub to 1.5 ft	CO, w. to NV, s. to TX and S. CA; 3-8,000 ft	Dry, gravelly flats and draws	Livestock and wildlife browse
Black sagebrush <i>A. nova</i>	Small, decumbent shrub to 1.5 ft	General across eleven western states, esp. Great Basin; 5-8,000 ft	Shallow, stony, often calcareous soils	Winter browse for wildlife and sheep
Budsage <i>A. spinescens</i>	Low, rounded, spiny shrub to 1 ft	MT to OR s. to S. CA and NM; 3-7,000 ft	Dry, often saline plains and hills	Winter and spring browse for wildlife and livestock
Cleftleaf sagebrush <i>A. arbuscula</i> ssp. <i>thermopola</i>	Dwarf, spreading, lax shrub to 1 ft	W. WY and N. UT w. to OR; 5-9,000 ft	Dry, rocky soils often with a shallow restrictive layer	No known browse use
Fringed sage <i>A. frigida</i>	Mat-forming subshrub sometimes to 1 ft	Circumboreal, s. thru W. US and Canada into Mexico; 4,500-11,000 ft	Typically dry, coarse soils; wide variety of sites	Soil stabilizer; variable browse use by location
Low sagebrush <i>A. arbuscula</i> ssp. <i>arbuscula</i>	Low, spreading, irregular shrub to 1.5 ft; some layering	WA to CA e. to WY and CO; 2,500-7,000 ft	Dry, rocky, often alkaline soils, usually with shallow restrictive layer	Variable browse use by location
Plains silver sagebrush <i>A. cana</i> ssp. <i>cana</i>	Erect, freely branching shrub to 5 ft; sprouts and layers	N. Great Plains, Canada to NE; 4-7,000 ft	Well-drained soils, alluvial flats and terraces	Winter livestock and big game browse
Sand sagebrush <i>A. filifolia</i>	Erect, branching shrub to 4.5 ft	NV e. to WY and NE, s. into Mexico; 2-6,000 ft	Dunes, hills and other deep sands	Soil stabilizer; variable browse use
Wyoming big sagebrush <i>A. tridentata</i> ssp. <i>wyomingensis</i>	Low, many-branched, uneven shrub to 2 ft	General across eleven western states; 5-7,000 ft	Dry, shallow, gravelly soils	Winter browse for sheep and big game



Figure 4.--Plains silver sagebrush (*A. cana* ssp. *cana*) occurring on a well-drained alluvial terrace in eastern Wyoming, an example of sagebrush taxa adapted to sites of medium productive potential.

Low sagebrush (*A. arbuscula* ssp. *arbuscula*) and its closely related taxon cleftleaf (hotsprings) sagebrush (*A. arbuscula* ssp. *thermopola*) both occupy areas with an impermeable restrictive layer close to the soil surface, or with high volumes of gravel throughout the profile. Although the shallow soils tend to become waterlogged in the spring, both they and the gravelly soils become extremely dry by midsummer, creating high water stress. In some locations, low sagebrush has excellent browse values for sheep and mule deer (Sheehy and Winward 1981). Normally, neither low nor cleftleaf sagebrush stands are amenable to control efforts, due to the limiting conditions of their sites. Occasionally, however, the taxa form nearly a monoculture. To restore these areas to better ecological condition, some of the shrubs must be removed to provide an opportunity for herbage increase. But the treatment programs must be conducted carefully (Winward 1980).

Black sagebrush (*A. nova*) normally occurs on shallow, stony, and often calcareous sites of limited productive potential. It is generally thought to be palatable to wildlife and domestic sheep, although there are geographic variations in browse value. Where found to be in low ecological condition, there is some potential for improvement of black sagebrush sites through reseeding (Winward 1980). Because of limiting site conditions, however, control programs must be based on a full consideration of site values and conducted with care.

Wyoming big sagebrush (*A. tridentata* ssp. *wyomingensis*), the most xeric member of the *A. tridentata* complex, is distributed generally throughout the sagebrush region on sites of medium potential, usually dry, shallow, and rocky soils. The browse value of Wyoming big sagebrush is only moderate, but due to its locations it is often a staple on big game winter range, especially those of deer and antelope. The combination of browse value, geographic location, and xeric site has produced a low ecological condition in a high percentage of the type. Increased forage

production is highly likely either through release of native species or seeding of introduced varieties. Therefore the management potential of Wyoming big sagebrush is high, but xeric conditions make sensitive treatment necessary (Winward 1983).

With a circumboreal distribution extending all the way into Mexico through western North America, fringed sage (*A. frigida*) is by far the most cosmopolitan *Artemisia*. Fringed sage occupies a wide variety of soils, ranging from low semidesert to moist subalpine sites, doing best on dry, shallow, rather coarse soils (USDA Forest Service 1937). As a result, it is a common associate in many different plant communities and an excellent pioneer in disturbed areas, where its mat-forming growth form makes it a valuable soil stabilizer. Its browse value varies considerably with site and season, but often provides valuable forage for many grazing animals. Due to its wide occurrence and distribution, fringed sage imposes no particular constraint on the development of management programs.

The moderate-potential species considered within an IPM context offer a wide range of management options. But each option can be properly exercised only after a detailed site analysis to develop an appropriate management prescription.

Sites of High Productive Potential

The sagebrush species occurring on sites of high productive potential are adapted to deep, well watered, fertile soils (see Table 4). As a consequence, they have received the bulk of the control programs to date (Wyoming big sagebrush, a moderate-potential species, may have received more treatments than any other *Artemisia*, due to its extent and location). Their abundance, productivity, and ecological flexibility have made them of primary importance in management programs such as IPM. The most efficient and effective strategy, however, continues to be based on a site appraisal in relation to management goals.

For instance, mountain silver sagebrush (*A. cana* ssp. *viscidula*) is a high-elevation taxon normally occurring on sites with high seasonal water tables--streamsides, swales, meadows, and areas of lingering snow. Its well-watered habitat usually supports a diverse herbaceous flora. But because the shrub both layers and sprouts, and is not particularly palatable to either livestock or wildlife, it can become very dense (Winward 1980). Under such circumstances, it is proper to carefully reduce the shrub population in such a way as to preserve and encourage growth of the resident herbaceous flora.

Similarly, tall threetip sagebrush (*A. tripartita* ssp. *tripartita*) is a ready increaser under most conditions, especially disturbance, due to its vigorous layering and sprouting capability. High density populations of the shrub can occur irrespective of grazing management because of its occurrence on moderately deep, well drained, productive soils. In addition, the shrub is of low palatability to both livestock and big game (Brunner 1972). These characteristics indicate that it is profitable to reduce stands of tall

Table 4.--Taxa of Artemisia adapted to sites of high productive potential

Taxa	Growth form	Distribution	Habitat	Latent Value
Basin big sagebrush <u>A. tridentata</u> ssp. <u>tridentata</u>	Erect, heavily branched, uneven shrub to 6 ft; sometimes to 15 ft	B. Col. s. to Baja CA, e. to ND and NM; 4-7,000 ft	Deep, mod. dry, drained soils of plains, valleys and lower foothills	Good thermal cover; little browse use
Mountain big sagebrush <u>A. tridentata</u> ssp. <u>vaseyana</u>	Uniform, flat-topped shrub to 3 ft; frequently layers	General across sagebrush region; 6-10,000 ft	Deep, well-watered and well-drained soils of foothills and mountains	Winter browse for wildlife
Mountain silver sagebrush <u>A. cana</u> ssp. <u>viscidula</u>	Erect, freely branching shrub to 3 ft; sprouts and layers	Cont. Div. w. across sagebrush region; 6-10,000 ft	Streamsides, meadow margins and other moist soils	Little browse use
Subalpine sagebrush <u>A. tridentata</u> ssp. <u>spiciformis</u>	Uniform, flat-topped shrub to 3 ft; layers	Disjunct at high elevations in CO, WY, and UT; 8,500-11,000 ft	Deep, well-watered soils, high mountains	Little browse use
Timberline sagebrush <u>A. rothrockii</u>	Low, flat-topped shrub to 2.5 ft; layers	Widely disjunct at high elevations in Sierra Nevada, CA; 8,500-11,000 ft	Deep, well-watered soils, high mountains	Little browse use
Tall threetip sagebrush <u>A. tripartita</u> ssp. <u>tripartita</u>	Erect, freely branching shrubs to 6 ft; sprouts and layers	B. Col. s. to W. MT, N. UT, and NV; 3-7,500 ft	Dry, well-drained loams	No apparent browse use

threetip sagebrush, but that control programs must be conducted with care. Most likely, treatment will have to be repeated periodically.

The most common taxon within the section Tridentatae, widely regarded as the archtypical sagebrush, is basin big sagebrush (A. tridentata ssp. tridentata). Basin big sagebrush is the most widespread and common shrub in western North America, especially in the Great Basin (McArthur et al. 1979). On lowland ranges below 7,000 ft, it forms extensive stands over plains, valleys, and foothills. Its distribution is based on its wide ecological amplitude, especially in its adaptation to soils ranging from strongly alkaline to strongly acid. Optimum growth is in deep, fertile, well-drained soils; as a consequence the shrub has long been used as a rule-of-thumb indicator of arable soils. Much of the type has been converted to cultivation. Although basin big sagebrush provides good cover for wildlife, it probably has the lowest palatability and browse value of the A. tridentata subspecies. Although its morphological and ecological characters suit it to control programs, past treatments have severely reduced the overall acreage of basin big sagebrush useful in IPM.

Of more immediate management practicality is a prominent shrub occupying foothill and mountain ranges throughout the sagebrush region, mountain big sagebrush (A. tridentata ssp. vaseyana). Ranging to the upper elevational limits of the sagebrushes, mountain big sagebrush^{1/} normally occurs on deep, moist, well drained soils. Its palatability and forage value is often important to

wintering big game, and mountain big sagebrush sites commonly support large numbers of productive herbaceous species. The shrub has a high potential for increase in density, regardless of ecological or management conditions. Periodic control efforts may be useful in keeping the shrub at acceptable levels and increasing herbaceous forage production (Figure 5). A high percentage of all control programs carried out to date have been on mountain big sagebrush sites (Beetle and Johnson 1982).

Two subalpine taxa occur in the sagebrush region. Both normally are found at forest margins and in



Figure 5.--A dense stand of mountain big sagebrush (A. tridentata ssp. vaseyana) in south-central Wyoming, typical of mountain areas throughout the sagebrush region. Mountain big sagebrush exploits sites of high productive potential; note the successful removal of the shrubs and the resultant increase in forage production.

^{1/} Goodrich et al. (1985) have divided mountain big sagebrush into a typical form with large heads of 7-11 flowers, common in the upper elevations of the Northwest (f. spiciformis in the Beetle [1960] nomenclature), and a small-headed, few-flowered (4-6) phase widespread in most of the western states, named A. t. ssp. vaseyana var. pauciflora.

openings on deep, well-watered soils of high productive potential limited by a short growing season. Therefore, both have the same ecological and management characters as mountain big sagebrush, except for a tendency to layer and sprout. Their high elevation distribution make them of little practical browse value. The two taxa are separated mainly on the basis of geographic distribution. Timberline (Rothrock) sagebrush (*A. rothrockii*) is a shrub of the Sierra Nevada and San Bernardino Mountains of California, notable for purple pigment in the involucres and dark green leaves. Subalpine sagebrush (*A. tridentata* ssp. *spiciformis*) occurs in the central Rocky Mountains as the upper elevation member of the mesic gradient series for the species (Goodrich et al. 1985). Although both taxa respond readily to control measures, their limited occurrence, resprouting tendencies and short growing seasons make them problematic in IPM programs.

Thus mountain big sagebrush and the other high-potential taxa form the logical end point of the ecological continuum originating with the species inhabiting low-potential sites of limited distribution. While IPM programs can seldom be justified for low-potential species, they can generally be applied to many moderate-potential and most high-potential species on a site-specific basis. For these types, IPM is cast against a wide background of management opportunities.

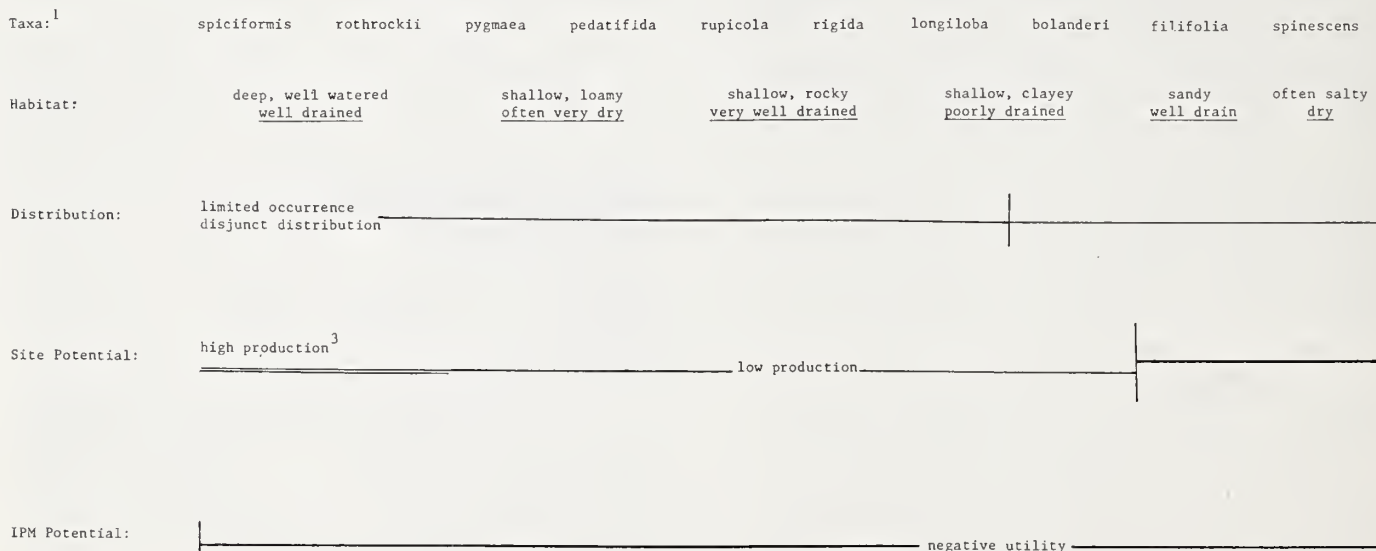
The IPM Potential of the Sagebrushes

The relative utility, or simply IPM potential, of the sagebrush taxa in management and control programs can be derived from the ecological continuum

of Figure 6. In this construct, the zone of negative utility includes the six taxa of constricted distribution adapted to sites of low productive potential, three species with high intrinsic values inhabiting medium-potential sites, and two high-elevation species of limited distribution with short-season productive potentials. There is not a sufficient rationale to conduct control programs on these taxa because replacement vegetation will be difficult to establish, probably of inferior adaptation to site conditions, and likely of no higher utility than resident species. The sites are better left unaltered, with management based on successional goals.

The zone of possible utility centers on the six remaining taxa of medium-potential sites, all having at least fair utility as seasonal browse for some animals on some sites. All have important roles as site dominants and soil stabilizers, but are often in poor ecological condition. Given specific management objectives, carefully planned and implemented control programs may be used to improve ecological conditions, or to capitalize on better-than-average growing conditions of some sites. Such programs can be significant for some species. Wyoming big sagebrush, for example, has received extensive treatments based on site potentials.

The zone of positive IPM utility is drawn entirely from species of very wide occurrence and distribution occupying sites of high productive potential. These species derive their productivity mainly from the deep, well-watered and drained soils supporting them, although most have a wide adaptation to a variety of sites across large areas



¹Taxa are identified by their lowest-rank epithets---subspecies or species.

²Distribution of *A. tripartita* is mainly regional.

³Limited by short growing season.

Figure 6.--The sagebrush taxa arranged as a continuum of IPM potential, based on habitat, distribution, and general site potential.

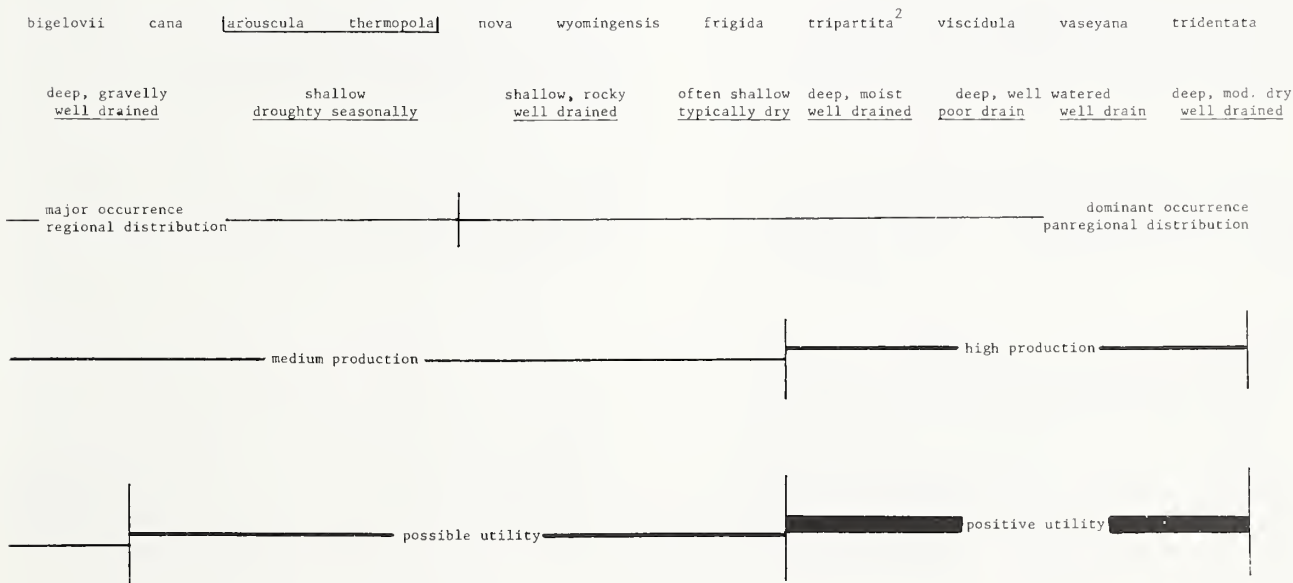
of the sagebrush region. Therefore control efforts in this zone have a high probability of success in establishing replacement vegetation, and an equally high probability of improving ecological condition and forage production. Further, these goals can be achieved through a variety of treatment prescriptions tailored to the ecological characters of the site.

Of the twenty-one sagebrush taxa considered here, eleven are deemed to be of negative utility, six are of problematic worth, varying from seldom to frequent application, and only four are thought to be of direct and general relevance to IPM programs. Remembering that each species on each site will have its own unique requirements, the general approach outlined can help define Integrated Pest Management programs in the western sagebrush ecosystem.

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WEED AND BRUSH CONTROL TACTICS IN THE SAGEBRUSH ECOSYSTEM

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ABSTRACT

Brush and weed control on sagebrush-grass rangelands are important examples of integrated pest management. The necessity to control sagebrush is paramount for rangeland improvement either to release desirable understory species or in preparation for seeding. Many brush control methods have been developed, including mechanical, chemical, and prescribed burning. In many instances, control of herbaceous range weeds is also necessary to establish forage and browse species and to negate poisonous and noxious weed problems. The integration of brush and herbaceous weed control with revegetation is an effective technology for range improvement in many degraded sagebrush communities.

INTRODUCTION

Vegetation changes in the sagebrush (*Artemisia*)/grasslands of western North America have been influenced by man since the late 19th century, when livestock were introduced to the sagebrush rangelands (Young et al. 1984). The development of mechanical, herbicidal, and prescriptive burning technology have provided range managers with the tools to effectively control brush and weeds in the sagebrush ecosystem.

Matching the weed control methodology with the site is always a difficult task. The land manager must be capable of evaluating sites with differing potentials and of selecting methods which will help achieve the management objectives for an allotment. The goals of weed and brush control on sagebrush rangelands are to obtain a stable mixture of forbs, grasses, and shrubs, and to have the least impact on the environment.

The expected benefits of a weed control program should outweigh the risks of the project. Land managers must be able to include a treated area in a management program that will allow the utilization of the expected improved forage production by domestic livestock or wildlife.

Sagebrush control without having desirable species present to respond to the treatment or without seeding of forage and browse species can release undesirable plants like horsebrush (*Tetradymia canescens*), green rabbitbrush (*Chrysothamnus viscidiflorus*), or cheatgrass (*Bromus tectorum*) (Young et al. 1982).

The available manipulation options for sagebrush control fall into three major categories: herbicidal, mechanical, and prescribed burning.

HERBICIDES

The discovery of 2,4-D (2,4-dichlorophenoxy) acetic acid as a plant growth regulator during World War II led to the development of herbicides for control of sagebrush (Bovey 1971, Young et al. 1984).

Big sagebrush (*Artemisia tridentata*) is readily controlled with 2 lb acid equivalent of low-volatile ester formulation of 2,4-D per acre (2.25 kg/ha). The best results are obtained when the sagebrush is actively growing in the spring and moisture is still available in the soil profile for plant growth (Evans et al. 1979, Blaisell et al. 1982).

There are two major options in using a herbicide program to control sagebrush; spray to remove competition by brush and thereby release understory vegetation, and spray and then seed desirable forage.

Removing Competition

This option is adapted to range sites in fair to good ecological condition, where there is an adequate stand of desirable perennial grasses present to respond to the release of the site from sagebrush dominance (Blaisdell 1982). One rule of thumb used by range managers is when one can step from one desirable grass to another, the site is suitable for big sagebrush control with herbicides.

Major advantages of herbicidal brush control are: (1) it maintains the desirable native grass species in the stand, and (2) it retains the integrity of the ecosystem with little or no soil surface disturbance.

Properly timed application of 2,4-D limits injury to desirable shrubs like bitterbrush (*Purshia tridentata*). Big sagebrush plants initiate growth and are susceptible to application of 2,4-D earlier in the spring than bitterbrush plants (Hyder and Sneva 1962).

The main disadvantages of the application of 2,4-D for the control of big sagebrush are the short-lived adverse effects on desirable forbs; the possible release of undesirable species like horsebrush, rabbitbrush, cheatgrass, and larkspur (*Delphinium depauperatum* and *D. glaucescens*) where an understory of desirable species is not present; and negative public socio-political attitudes about the use of 2,4-D.

More work needs to be done on the short- and long-term effects of 2,4-D applications on rangeland forbs (Blaisdell and Mueggler, 1956 Eckert et al. 1973). Each site should be evaluated for socio-political sensitivity, and careful consideration should be given to the vegetal composition when planning range improvement by spraying with 2,4-D to control sagebrush (Blaisdell et al. 1982).

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Spraying and Seeding

The second major option in using herbicides for sagebrush control is to spray the brush and then seed perennial grasses and forbs. This tactic is particularly advantageous when the range manager is working with low-condition sites that are completely dominated by sagebrush without an understory of desirable perennial grasses. These degraded sites often provide the most improvement potential on large range allotments where animal distribution is limited because of dominance by sagebrush. This tactic results in greater grazing management flexibility and more total forage production from treated areas and adjacent areas as well.

Sites selected for treatment by herbicide application and seeding techniques should have suitable terrain and soil for successful seeding and seedling establishment. They must receive adequate precipitation to assure establishment and survival of the planted species, and they must lend themselves to proper grazing management both for forage utilization and livestock distribution.

MECHANICAL BRUSH CONTROL

Chaining

Chaining involves pulling a heavy anchor chain between two large tractors to physically knock over and up-root large sagebrush plants to reduce competition with resident perennial grasses and forbs. Chaining works best with large, even-age class sagebrush. Where plants are small or of mixed ages, the chain tends to ride over the brush rather than uproot it.

Mechanical Brush Control and Seeding

The development of the brushland plow in 1947 and 1948 by Ted Flynn and Tom Coldwell provided an implement capable of effectively attacking dense stands of big sagebrush (Young et al. 1984). This development was the first major breakthrough for the mechanical manipulation of sagebrush dominated range sites. Plowing usually costs more and creates more disturbances of archaeological sites than the use of 2,4-D for control of big sagebrush.

Mechanical Removal of Aerial Portions of Big Sagebrush

An alternate approach to plowing or chaining is rotobating. Mechanical beaters originally developed for shredding corn stalks were adapted in the 1950's for rangeland brush control (Young et al. 1984).

Various models and types of beaters have been developed and tested by various manufacturers for over 30 years with varying degrees of success.

The main advantages of brush removal at or above the soil surface are less site disturbance than

chaining or plowing, and, in pure sagebrush stands, herbicides are not needed. Rotobating accomplishes little if root-sprouting shrubs are present.

Rotobeat-Seed-Herbicide Treatments

In northeastern California and northwestern Nevada, a popular combination approach to brush control in the sagebrush ecosystem is to mechanically remove the brush by rotobating, seed the area with an improved grass species, and then follow-up with a herbicide treatment two or three years later to control the undesirable sprouting brush species. This type of conversion has merit for fairly small pastures in an allotment or on private rangelands. It is not practical to convert vast areas of sagebrush into grass stands by this method because of the high cost for the combination of mechanical and chemical control.

PRESCRIBED BURNING

With the increasing socio-political concerns over the use of phenoxy herbicides on public lands, range managers have directed more of their time and attention to the prescriptive use of fire for sagebrush control.

A symposium on prescribed burning was held at Utah State University in March 1976. The proceedings published by the Utah Agricultural Experiment Station provide excellent reference information on many aspects of prescribed burning (Busby and Storey 1976). Another excellent state-of-the-art review on the use of fire in sagebrush/grass and pinyon/juniper communities was written by Wright et al. (1979).

Prescribed burning is used where an understory of desirable grasses and forbs can be released from the sagebrush dominance.

A prerequisite for a successful burn is to have sufficient dry understory fuels to carry the fire, and proper weather conditions to allow the fire to burn the brush without excessive damage to sensitive grasses and forbs. Most prescribed burning projects are attempted in early spring or early fall, with midsummer generally avoided because of excessive damage to perennial grasses (Blaisdell et al. 1982). Desirable forbs and browse species can also be adversely affected by burning at the wrong season (Blaisdell and Mueggler 1956). It appears that soil temperature and moisture conditions are important in regulating the intensity of fire and the resultant injury to desirable forbs and grasses.

At the present time, for many areas, the chief disadvantage of prescribed burning is the high cost of preparing the site and conducting the burn. If prescription conditions are not met during an appropriate interval, the project often must be delayed for a year before all conditions again become potentially correct for burning.

In some states like California, the high cost of liability insurance is also a major factor. How-

ever, the liability risks, if a prescribed burn escapes, require such an insurance policy.

On sites where horsebrush and rabbitbrush are present, resprouting can be a problem. Public sensitivity about air pollution also has to be considered.

Spring Burning

Early spring burning is preferred when sensitive grasses like Idaho fescue (*Festuca idahoensis*) and needle-and-thread (*Stipa comata*) are present in the treated area, or when bitterbrush is present. If the project site is properly prepared in advance, successful spring burns can be accomplished. The size of spring burning projects is often limited because prescription conditions seldom last more than 2 to 3 weeks.

Fall Burning

Fall prescription burns are best adapted to larger projects without an understory of sensitive grasses, or for sites where sensitive forbs are actively growing in the spring.

On some allotments it is necessary to exclude the area from grazing for one or two seasons to allow enough growth of low fuels to carry a fire.

Burning Followed by Seeding

As with herbicide application and seeding treatments, the first requirement is to remove the sagebrush; in this case, by burning rather than by herbicide application. The second, and probably the most critical step, is to seed the site in the same year as the burn with desirable perennial grasses and forbs, and not allow a weedy species like cheatgrass to colonize the released site (Young et al. 1976; Evans and Young 1978; Wright et al. 1979). The third requirement is to properly manage the site to maintain the improved vegetation after treatment and seeding.

UNDERSTORY WEED CONTROL

Understory weeds found in the sagebrush ecosystem generally fall into three categories; herbaceous weeds, poisonous plants, and noxious weeds.

Herbaceous Weeds

Brush control is obviously the major weed control problem on sagebrush rangelands, but the problem of competition from herbaceous weeds is also important. This is a much more complex problem than merely controlling a shrub to release established grasses. In many cases, annual grasses, cheatgrass, or medusahead (*Taeniatherum asperum*) must be controlled and then a perennial grass seeding established.

One tactic involves the use of the contact herbicide paraquat (1,1-dimethyl-4,4"-hipyridinium ion) followed by spring seeding (Evans et al. 1967).

Another involves the use of soil-active atrazine (2-chloro-4-(ethylamino)-6-(isopropyl-amino)-s-trizine) to create a fallow (Eckert and Evans, 1967).

Paraquat is sprayed in the spring after the annual weeds have germinated. To control broadleaf weeds, 2,4-D is added to the paraquat solution. The herbicide application is immediately followed by seeding. (Paraquat is ineffective in controlling medusahead east of the Cascades and Sierra Nevada mountains (Young et al. 1971)). For herbicide fallow, atrazine is applied in the fall. The herbicide is carried into the soil by winter precipitation, and the germinating annuals, both grasses and broadleaf species, are controlled the next spring. The fallowed areas are seeded after the season of weed control. The atrazine-fallow technique results in the accumulation of moisture and nitrates in the soil during the fallow period (Eckert et al. 1970). The year of fallow does not exhaust the supply of cheatgrass seeds in the soil, but the loss of litter on the soil surface reduces the potential of the seedbed and inhibits germination of the remnant seeds (Evans and Young 1970).

Considering the nature of the weed-control problem, it is a natural extension of the methodology to integrate technologies for control of herbaceous weeds and brush on sagebrush rangelands (Evans and Young 1977). Atrazine is applied to the standing brush in the fall and 2,4-D is applied in the spring. The herbaceous fallow channels the environmental potential (soil moisture, nutrients, etc.) to the shrubs, thus enhancing the probability for good brush control. The following fall, wheatgrasses are seeded through the standing, dead brush with a rangeland drill.

One of the latest developments in the use of herbicides on sagebrush rangelands is the renovation of the sparse stands of crested wheatgrass with applications of atrazine at 0.5 lb/A (Eckert 1979). This rate of atrazine does not injure established perennial grasses in this environment, but reduces the competition from annual weeds for one season, and gives the perennial grasses a chance to increase in vigor.

Poisonous Plants

Poisonous plants are, usually, locally spotty in occurrence and often are only problems to livestock during certain periods of the year. The major exception is halogeton (*Halogeton glomeratus*) which is widespread on poorer sites throughout several of the western states. Control efforts against halogeton have been frustrating because it is difficult to establish desirable plants on most sites where halogeton occurs (Cronin 1965).

Noxious Weeds

Noxious weeds are those species which are serious threats to high value croplands and are subject to eradication, quarantine regulation, containment, rejection, or other holding action at state or country levels. Some common noxious weeds found on

western rangelands include scotch thistle (Onopordum acanthium), leafy spurge (Euphorbia esula), dalmation toadflax (Linaria dalmatica), various knapweeds (Centaurea spp.), musk thistle (Carduus nutans), and numerous others.

The seriousness of a weed depends on its location, abundance, and difficulty to control. A weed that is considered a noxious weed in one state or county may not be similarly classified in another.

Many noxious weed species are aliens and often have highly developed vegetative reproductive capacity as well as abundant seed production. Noxious weed species are often candidates for biological weed control. The integration of biological control programs with management systems for rangelands is a tremendous challenge for land managers. Biological control influences total plant and animal ecosystems that interact, in many instances, with target species.

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ABSTRACT

Several physical and biological parameters govern the germination success of revegetation species in rangeland seedbeds. Seeding methodologies must conform to these constraints. Drills for seeding revegetation species consist of a storage box, metering device, furrow or drill opener, and a covering device. The rangeland drill can also be used for seeding in standing sagebrush. High technology drills are available with multiple drill boxes and openers. Research is needed on original seeding techniques.

INTRODUCTION

One of the important advances in agricultural technology during the 19th century was the perfection of drills for precisely metering and placing seeds in seedbeds. The name, drill, is derived from the drill or shallow furrow into which the seeds are dropped before being covered with soil. Drills replaced the haphazard method of broadcast seeding where metering and obtaining uniform distribution of the seed were difficult.

The desire to restore productivity of degraded rangelands created the need for a drill adapted to the specific conditions encountered on rangelands. Seedbed on sagebrush range sites can encompass rough topography, trash, and rocks.

Moisture Relations of Seeds in Seedbeds

Seeds have basic physiological requirements, centered on moisture relations, that must be met to ensure a chance for germination. To remain in a resting state, seeds must reach a moisture equilibrium of approximately 8 to 10 percent. Seeds in storage at markedly higher moisture contents will be subject to spoilage from microbial growth (Harrington 1973). Storage at very low relative humidities can result in embryo desiccation and excessive breakage when the dry brittle seeds are handled mechanically (Harrington 1972).

Seeds in equilibrium with the relative humidities of storage situations undergo a radical change in moisture relations when dropped into seedbeds. Because of their initial rather dehydrated state, there is a steep moisture gradient from soil water in the seedbed to the hydrating seed that is absorbing moisture (Shaykewich and Williams 1971). Obviously the flow of moisture from the seedbed to the seed will not occur if the soil water level in the seedbed is too low.

One factor that influences seedbed moisture levels and transfer to the seed is soil particle size (Collis-George and Sands 1959; Collis-George and

Hector 1966). The amount of moisture retained against gravity and the energy necessary to extract moisture from the films surrounding soil particles is a function of the soil particle size. Clay particles hold much more moisture than sand particles, but the water is more tightly bound to the soil particles in the case of the clay soil.

Soil particle size also influences the flow or hydraulic conductivity of moisture from the seedbed to the seed (Sedsley 1963). With a coarse textured seedbed, the relatively large soil particles have a limited number of points of contact with the seed. The finer the size of the soil particles, the greater the number of points of contact with the seed and the greater the potential hydraulic conductivity of solutions from seedbed to the seed. Obviously this can be partially compensated for by compressing the seedbed. This explains the farmer's old truism, "have a good firm seedbed." It also is the basis of the farmer's penchant for cultivating seedbeds mechanically to break down soil structural aggregates to obtain a fine seedbed.

Moisture relations in the seedbed become paramount when seeds are not covered, but are placed on the surface of the seedbed (Harper and Benton 1966). In this situation, the seed only has contact with the soil on its lower surface, roughly halving potential hydraulic conductivity. At the same time, the exposed surface of the seed has a potential negative moisture gradient to the atmosphere. The severity of this negative moisture gradient depends on the relative humidity of the atmosphere above the seedbed. In a humid environment this gradient may not inhibit germination. On semiarid rangelands, the moisture gradient from seeds to the atmosphere is steep and often inhibits germination.

The microenvironment of the seedbed can influence the severity of the moisture gradient from seeds to the atmosphere (Harper et al. 1965). A perfectly flat seedbed, free of stones or litter, presents an extreme environment for limiting germination. Herbaceous litter on the soil surface provides an excellent microenvironment for seed germination. Microtopography of the soil surface, if the seeds are fortuitously placed in desirable positions, provides a template where water vapor accumulates in depressions of the soil surface (Evans and Young 1972). Seeds in protected positions around stones also may benefit from improved moisture relations.

The harshness of seedbed surfaces apparently has been a selective factor that produced diverse species of plants that have evolved mechanisms to overcome the vicissitudes of this environment enough to germinate and establish. Some seeds have evolved self burial mechanisms to avoid the surface of seedbeds (Young et al. 1975). Other seeds have evolved some form of external seed mucilage that appears to aid in germination in such harsh environments (Young and Evans 1973). Mucilage apparently aids in germination by either increasing hydraulic conductivity from the seedbed to the seed, or by limiting moisture transfer from the exposed portion of the seed to the atmosphere. Mucilage has been associated with other diverse

functions in seed ecology ranging from aiding in seed dispersal to discouraging predation by rodents.

Temperature Relations of Seeds in Seedbeds

Soil is a relatively efficient insulator, so if a seed is placed at relatively shallow depths in the soil, it is insulated from the extremes in temperature found on the soil surface (Evans et al. 1970). The factor that controls the maximum depth to which the seed is planted is the length of the coleoptile or hypocotyl. Actually, optimum emergence is usually at some depth less than the maximum, because emergence requires an expenditure of stored energy by the seed. If the total energy reserve is exhausted in emergence, the seedling may subsequently succumb to a variety of stress factors before photosynthetic activity can generate additional energy.

There are two general types of seeds that must be planted at very shallow depths in the soil. One type does not have the potential to emerge from greater depths, and the other type requires extreme diurnal temperature fluctuations for germination. The germination of seeds of many species is inhibited by extreme diurnal fluctuation, but for some species, such extremes are necessary for germination. The influence of herbaceous litter on temperature relations is to modify or mollify the extremes in temperature fluctuations (Evans and Young 1970).

For a relatively few species, mainly semi-herbaceous species of the family Chenopodiaceae, it appears the optimum germination occurs on the soil surface. Why this requirement exists for these species is not known. The herbaceous chenopod Russian thistle (*Salsola iberica*) germinates so rapidly that germination can occur on the soil surface during brief transitory periods of adequate moisture (Wallace et al. 1968).

DESIGN OF DRILLS

The basic requirements of a drill are (1) a box to hold a supply of seed; (2) a metering device to precisely distribute seeds; (3) openers to make a furrow or drill in the seedbed into which seed is dropped; and (4) some method for covering the seed with soil (Young and McKenzie 1982).

The various components are usually carried on a trailer frame, with power for metering the seeds supplied by traction from the trailer wheels. Several sets of openers are usually mounted together to form a drill. The openers used for rangeland drills are usually spaced 12 inches (30 cm) apart.

Drill boxes are constructed of heavy gauge sheet metal. The volume of the box depends on the type of seeds being planted. Bulky grass seeds require proportionally larger boxes than dense, small-seeded legumes. Some form of agitation is required to keep the seeds from bridging across or packing in the box. Usually a rotating shaft with fingers

is used to stir the seeds. For awned seeds of native grasses that tend to pack in the drill boxes, counter rotating shafts have been used for agitation.

The most common form of seed metering device is a fluted shaft. As the shaft turns, seeds are trapped in the flutes and dropped into a tube that leads to the opener. A slotted closure can be adjusted to vary the exposed length of the fluted shaft and thus vary the seeding rate. A more precise metering system uses a rotating disk with slots machined to fit specific seeds. As the disk rotates through the drill box, seeds are captured, then ejected into the seed tubes. Seed tubes provide a flexible connection between the seed box and the opener. The connection must be flexible, because the openers are suspended and respond to irregularities in the seedbed.

There are a very large number of diverse openers used on drills. The most common opener for drills used to seed small grains is called the double-disk opener. With this opener, a small furrow is opened by the action of two flat disks mounted on a shaft so they form a forward facing V. Much of the crested wheatgrass (*Agropyron desertorum*) seeded on the northern Great Plains and in the Intermountain Area was seeded with this type of drill.

Development of the Rangeland Drill

The need for the rangeland drill was actually spawned in a large part by the development of the brushland plow by the Rangeland Seeding Equipment Committee. The federal land management agencies formed this interagency committee after World War II to develop equipment for seeding rangelands. The plow was designed to plow brush on rough, rocky sites. This process left a very rough seedbed with a lot of trash on the surface. Such conditions led to excessive breakage of double-disk openers.

The rangeland drill copied the rangeland plow in that each opener was suspended independently so it could rise over obstructions. In addition, the rangeland drill was a very heavy and ruggedly-constructed piece of equipment. Large diameter wheels allowed the drill to easily ride over obstructions. The large wheels also helped reduce the power requirement for towing the implement, even in rugged topography. A rangeland drill can be easily pulled by a 35 horsepower (25 kw) wheeled tractor.

The rangeland drill used single-disk openers. Each disk was dragged through the seedbed at a slight angle held by a rigid arm. The depth of the small furrow opened by this system was highly dependent on soil conditions in the seedbed. Seed coverage with this system was accomplished by chain drags or pipe drags.

The original rangeland drill was an engineering success capable of seeding under very rugged conditions. However, seed placement and coverage under certain seedbed conditions was very much a hit or miss situation.

Modified Rangeland Drill

The establishment of wheatgrass seedlings on sagebrush rangelands is often enhanced by seeding in a deep furrow (Evans et al. 1970). The furrows moderate the microenvironment in terms of temperature and moisture.

Almost as soon as the original rangeland drill became available in 1956, range managers bent the arms and added weight to the arms in order to make deeper furrows. In response to demands for a deep furrow drill, modified arms adjustable in two planes were developed and tested (Asher and Eckert 1973). These massive arms required a 21-inch (52.5 cm) spacing.

Seeding Mixtures

The rangeland drill can be equipped with special drill boxes for metering seeds of markedly different sizes. The main box can be used for wheatgrass and similar seeds and a small box for small-seeded legumes. This takes care of metering seeds of different sizes, but both types of seed drop down the same seed tube to the opener.

Small seeds also can be dispersed in the main seed box of a rangeland drill by using some inert material such as rice hulls or vermiculite to increase the volume of material seeded. The same basic problem exists with the dispersal system that occurs with multiple drill boxes, however; the mixture of seeds is planted with the same opener.

Obviously, seeds of different species may have different depth and covering requirements for optimum germination. There may or may not be sufficient overlap in requirements for a mixture of seeds to germinate at a given depth. Depth of planting and soil coverage of the seed are critical for seed germination and seedling establishment. While grain drills have been developed with press wheels that firm soil coverage after the seed has been planted, the only drills for rangelands with this type of seed coverage devices are the new high technology drills.

Seeding through Brush

The rangeland drill has the capability of seeding through standing, but dead, big sagebrush (Kay and Street 1961). This capability opens up the possibility of revegetating systems where herbicides are used to kill the brush and/or herbaceous weeds and the area is seeded without mechanical removal of the brush. This system has already been widely used to seed big sagebrush areas without a cheatgrass (*Bromus tectorum*) understory. Seeding through standing brush with a rangeland drill requires a considerably larger tractor (50 horsepower, 265 kw) and may present a hazard to pneumatic tires.

High Technology Drills

Several brands of high technology drills are currently available commercially, from either domestic or foreign manufacturers. Some of these

drills were developed in New Zealand for revegetation of grazing land. These high technology drills have multiple drill boxes and openers so that seeds of different species can be seeded separately in one pass. These drills are very expensive, reflecting their high level of technological development. The high technology drills obviously are not as rugged as the rangeland drill, but they can be used on selected rangeland sites.

Imprinters

A novel method of seedbed preparation involves shaping the seedbed into a desirable microtopography for seedling establishment through the use of a heavy roller equipped with a patterned surface. The pattern on the surface of the roller presses depressions and ridges in the seedbed. Seeds are metered from a traction driven or powered broadcast seeder either before or after the seedbed is imprinted. Tests of this implement in a variety of rangeland ecosystems are needed in order to evaluate its potential.

Experimental Drills

The Arid Land Seeder has been under development for several years in New Mexico (McKenzie and Herbel 1982). It features an integrated mechanical system for brush control, seeding, and seedbed modification. The brush is cut off below the surface with a root plow, elevated over the drill, and scattered as a mulch on top of the seedbed. Recently, a rangeland seeding machine has been developed at Miles City, Montana.

Original ideas for seeding equipment need to be fostered. This is especially true considering the diversity of new plant material that is about to become available for revegetation of rangelands.

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ABSTRACT

Resistant cultivars are particularly important in the management of plant pests on western rangelands and in many cases may be the only economically feasible method. Although genetic resistance to damaging plant pests has been reported in several forage species adapted to range, very little breeding work has been done to incorporate these genetic factors into resistant cultivars. Intercharacter relationships must be considered in breeding for pest resistance. For example, cultivars bred for improved nutritional value may be preferred by insects and diseases as well as by larger grazing animals. Most of the grasses used for revegetation in the sagebrush ecosystem were introduced from Asia or Europe. Early seedlings were often made with unimproved seedlots, or with cultivars developed for the northern Great Plains; however, several improved varieties have recently become available. Crested wheatgrass, Agropyron cristatum (L.) Gaertn. and A. desertorum (Fisch. ex Link), a cool season species-complex indigenous to Eurasia, has been the most widely used grass for reseeding depleted ranges of western U.S. and Canada. The cultivars 'Nordan' and 'Fairway', were the first improved cultivars of crested wheatgrass used in North America. Recently released cultivars include 'Ephraim', 'Ruff', and 'Hycrest'. The latter, a hybrid between induced tetraploid A. cristatum and A. desertorum, has been particularly impressive in evaluation trials. Germplasm of Russian wildrye, Psathyrostachys juncea (Fisch.) Nevski, recently obtained from the USSR has been more productive and easier to establish on range sites than the commonly used cultivar 'Vinall'. 'Prairieland', a new cultivar of Altai wildrye, Leymus angustus (Trin) Pilger, has shown particular promise as a source of fall and winter forage. The USDA-ARS is cooperating with Utah State University in a breeding program to develop new range grasses through interspecific hybridization. After eight generations of selection, a potentially valuable breeding population has been obtained from a hybrid between quackgrass, Elytrigia repens (L.) Nevski, and bluebunch wheatgrass, Pseudoroegneria spicata (Pursh) Love. Several other hybrid derivatives are being evaluated.

INTRODUCTION

Resistant grass cultivars can form the foundation to build an integrated system of pest control on western range. On many range sites with a limited economic value per unit area, the use of resistant cultivars may be the most practical method of

controlling plant pests. Adkisson and Dyck (1980) discussed how cultivars with varying levels of resistance could be used effectively in integrated pest management. They listed the following advantages of resistant plant materials: (1) Pest control through resistance is cumulative and economical. (2) Resistance developed in plants to one pest species also may provide resistance to several others. (3) Reduction in vigor and number of insect pests makes them more vulnerable to natural predators and other control methods. Even a low level of resistance may, in combination with natural enemies, effectively control a pest when either method is inadequate when used alone. (4) Incorporation of resistant cultivars conserves natural enemies and is in harmony with environmental quality considerations.

Removal of undesirable plants and reseeding with improved and often introduced grasses have usually resulted in increased production of forage for livestock and wildlife. Drastic changes in the plant community, however, can upset certain self-regulating balances between plant pests and their hosts, paving the way for new and often more complex pest problems than previously encountered. Increased infestations of native grass bugs (Labops and Irbisia spp.) on monocultures of introduced wheatgrasses are typical examples. These maladies should not discourage intensive breeding research to increase the pest resistance levels of new plant materials.

RESISTANCE TO INSECTS AND DISEASES

Improving the level of resistance to plant pests (primarily insects and diseases) has been and is a major objective of most plant breeding programs in the more humid regions of the U.S. Examples of significant genetic progress could be cited in several crops including small grains, sugarbeets, corn, cotton, forage legumes and grasses, and others (Maxwell and Jennings 1980). It is evident that heritable genetic variation exists for mechanisms conditioning resistance to insects and diseases in plant species adapted to western rangeland. Watts et al. (1982) reported that within the past 10 years, resistance to 26 pest species representing 7 orders of insects have been recorded in the entomological literature. Very little breeding work, however, has been done to incorporate these genetic factors into resistant cultivars.

Hewitt (1980) found differences among 10 wheatgrasses in tolerance to feeding by the black grass bug, Labops hesperius Uhler. He concluded that tall wheatgrass, Thinopyrum ponticum (Podp.) Barkworth and D. R. Dewey, slender wheatgrass, Elymus trachycaulus (Link) Gould ex Shinners, and intermediate wheatgrass, or pubescent wheatgrass Thinopyrum intermedium (Host) Barkworth and D. R. Dewey, could be used for reseeding areas where black grass bugs are likely to be a problem. In earlier studies, Higgins et al. (1977) reported that intermediate wheatgrass and Kentucky bluegrass, Poa pratensis L. were susceptible to feeding injury by the grass bugs.

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Hansen et al. (1985) found significant differences in feeding preference of the black grass bug for 16 grass species and interspecific hybrids grown in monoculture and in mixed stands in the greenhouse. In their studies, orchardgrass, Dactylis glomerata L., and reed canarygrass, Phalaris arundinacea L., were least preferred by the bugs, while Fairway crested wheatgrass, Agropyron cristatum (L.) Gaertn., and intermediate wheatgrass were most favored. Variation within species suggested that breeding for resistance would be effective. Haws et al. (1978) also demonstrated that range grass species differed markedly in resistance to the black grass bug. They are actively involved in research to characterize the plant factors associated with the differential response among species. Using the scanning electron microscope, they found distinct differences in the structure of resistant and susceptible species. They also demonstrated that genetic differences in resistance to the grass bug occurred within species. Procedures are presently being developed to screen large plant populations for resistant germplasm.

Asay et al. (1983) found significant differences among and within several species and interspecific hybrids of range grasses in resistance to the bluegrass billbug, Sphenophorus parvulus (Coleoptera: Curculionidae). Slender wheatgrass and related species were particularly susceptible. Crested wheatgrass, thickspike wheatgrass, Elymus lanceolatus (Scribn. & Smith) Gould, Russian wildrye, Psathyrostachys juncea (Fisch.) Nevski, and salina wildrye, Leymus salinus (M.E. Jones) A. Love, were relatively resistant to the insect. Significant differences occurred within a breeding population of a hybrid quackgrass between Et. repens (L.) Nevski and bluebunch wheatgrass, Pseudoroegneria spicata (Pursh) Love. A broad-sense heritability of over 50% suggests that excellent opportunities were available to select for increased resistance in this hybrid. Significant differences in resistance to the billbug also have been reported in Kentucky bluegrass by Lindgren et al. (1981) and Kindler and Kinbacher (1976).

In many instances, natural selection has effectively developed a biological balance between plants native to western range and their pathogens and pests. Braverman (1967) and Braverman and Oakes (1972) provided comprehensive literature reviews concerning disease resistance in warm- and cool-season forage and turf grasses. They cited several examples of resistance in the wheatgrasses, the wild ryegrasses, and other range species to several diseases including rusts, smut, bunt, blight, and viruses. Berkenkamp et al. (1972) discussed the diseases prevalent in the wheatgrass and wildrye species in Alberta. They found significant differences among 11 Russian wildrye cultivars in resistance to powdery mildew, spot blotch, and leaf rust, suggesting that genetic progress could be made through hybridization and selection. Andrews (1953) also has demonstrated that the general level of resistance of crested wheatgrass to Helminthosporium sativum could be substantially increased using a simple

mass selection procedure. Several workers have attempted to transfer disease resistance inherent to species such as tall wheatgrass and pubescent wheatgrass to cultivated wheat. Agrotriticum hybrids have been produced that are more resistant to several diseases than wheat (Braverman 1967).

NEMATODES

Nematodes are known to reduce the productivity of range grasses, although the extent of damage has not been documented (Griffin 1984). These organisms decrease the drought resistance of the grass plant by obliterating, compressing, or interrupting the vascular system. Meloidogyne spp. are among the most aggressive nematodes that infest grasses. Griffin et al. (1984) studied the response of seven grass species to the Columbia root-knot nematode, M. chitwoodi. They concluded that orchardgrass was a very good host, while western wheatgrass, standard crested wheatgrass, and smooth brome grass were good hosts. Great Basin wildrye was a poor host and bluebunch wheatgrass and intermediate wheatgrass were nonhosts. The frequency of resistant plants within species indicated that genetic variability was available to facilitate selection for resistance to this potentially destructive pest.

INTERCHARACTER RELATIONSHIPS

Carlson (1974) found that stem rust significantly lowered the nutritional value of orchardgrass. When rust was present in the autumn, a significant ($P < 0.01$) negative correlation ($r = -0.84$) was detected between disease ratings and digestibility. He conducted a recurrent selection program for rust resistance using germplasm from the cultivar 'Sterling'. Digestibility of resistant plants from this program was as much as 11.6 units higher than the original Sterling when rust was prevalent. The strains were not significantly different when Sterling was free of rust. Carlson concluded that when rust is a serious problem in orchardgrass, marked improvement in quality can be achieved by breeding for rust resistance.

Conversely, breeding for increased forage quality can lower disease resistance. Workers at the Welsh Plant Breeding Station conducted three cycles of selection for increased levels of water soluble carbohydrates in perennial ryegrass, Lolium perenne L. Their selection was effective, and, after three cycles, the high lines averaged 20 percent water soluble carbohydrate and the low lines 15 percent. However, some negative relationships were of concern. Susceptibility to crown rust was substantially increased in the high population. Average disease ratings (1-5 scale) were 2.7 for the high carbohydrate lines and only 1.2 for the low lines (Vose and Breese 1964).

Insects apparently attack the most nutritious components of the forage and reduce both yield and quality (Watts et al. 1982; McKendrick and Bleicher 1980). Survival and growth rate of crickets, Acheta domesticus L., on diets of various forages have been positively correlated

with large animal performance in trials conducted at Missouri (Pfander et al. 1964; Stone and Matches 1966). In subsequent trials, crickets were used as test animals to detect genetic differences in forage quality among strains of tall fescue, Festuca arundinacea Schreb. Significant differences in survival and growth rate of the crickets were found (Asay et al. 1975). This relationship merits some concern in breeding for resistance to insects. Insects, like disease organisms, lower the quality of the forage, and plant breeders may inadvertently lower the resistance of plants to insect infestations by increasing the forage quality.

PLANT MATERIALS FOR REVEGETATION

Most grasses used for revegetation in the sagebrush ecosystem were introduced from Asia and Europe. Early seedlings were made with unimproved seedlots or cultivars developed for other areas such as the northern Great Plains. Although comparatively little breeding work has been done with range grasses, particularly those adapted to the sagebrush ecosystem, several improved cultivars have been recently developed. With the availability of better and more diverse plant materials, plant communities representing grasses, forbs, and shrubs are replacing the traditional monocultures in range seeding programs.

Introduced Species

Crested Wheatgrass

Crested wheatgrass has been the most widely used grass for seeding rangelands of Western U.S. and Canada. The grass, which is native to Eurasia, was successfully established in North America in 1906 after an earlier introduction failed (Dillman 1946). Crested wheatgrass is actually a complex of diploid ($2n=14$), tetraploid ($2n=28$), and hexaploid ($2n=42$) species. In North America, the diploids are represented by Fairway, Agropyron cristatum (L.) Gaertn., and the tetraploids by Standard, A. desertorum (Fisch. ex Link) Schult., and Siberian, A. fragile (Roth) Candargy.

Crested wheatgrass is an excellent source of early season forage in the sagebrush ecosystem; however, its quality declines rapidly during the summer and fall. For optimum returns, it should be used most heavily during the spring in a seasonal rotation with later-maturing grasses. Primarily a bunchgrass, it is resistant to drought and cold. It is best adapted to areas with from 23 to 40 cm of annual precipitation at altitudes under 2,500 m. It is not as tolerant of salinity as tall wheatgrass, quackgrass, or slender wheatgrass. Crested wheatgrass is an excellent seed producer and is comparatively easy to establish on semiarid range (Asay and Knowles 1985; Rogler 1973).

The first products of crested wheatgrass breeding programs were the tetraploid (Standard) cultivars 'Nordan' and 'Summit' and the diploid cultivar 'Fairway.' Nordan was released in 1953 by the USDA/ARS Northern Great Plains Research Center at Mandan in cooperation with the North Dakota

Agricultural Experiment Station (AES). The parental materials from which it was derived were introduced from the plains of USSR. Nordan is particularly noted for its relatively large seeds, good seedling vigor, and upright growth habit (Rogler 1954; Asay and Knowles 1985). Summit, which was developed by Agriculture Canada at Saskatoon, Saskatchewan, was also released in 1953. Although the cultivar produces abundant forage yields, its popularity has been limited by problems associated with seed processing (Hanson 1972).

In 1953, the USDA/SCS and the Idaho AES released 'P-27', a strain of the Siberian type. Its parental germplasm was originally derived from Kazakhstan, USSR. Siberian is similar to Standard and is characterized by narrow, awnless spikes and fine, leafy stems. It is reported to be particularly well adapted to light, droughty soils (Hanson 1972).

The diploid Fairway was the first cultivar of crested wheatgrass released in North America. It was developed from a Siberian introduction (PI 19536) by Agriculture Canada at Saskatoon and released in 1932. Fairway is considered to be leafier and of higher quality, but somewhat less drought resistant, than the Standard cultivars. 'Parkway', another diploid cultivar, was developed at Saskatoon and released in 1969. It was selected from Fairway primarily on the basis of improved vigor, plant height, and leafiness (Elliott and Bolton 1970; Hanson 1972).

The cultivars 'Ephraim' and 'Ruff' are recent additions to the list of available cultivars of crested wheatgrass. Ephraim was released in 1983 by the USDA/Forest Service, Utah State Division of Wildlife Resources, and USDA/SCS in cooperation with the Utah, Arizona, and Idaho AES. The parental germplasm was obtained from near Anakara, Turkey. It is a persistent, drought resistant cultivar that was selected primarily for its sod-forming characteristics. Although rhizome development by the cultivar is influenced by environmental conditions, rhizomes reportedly occur by the second or third year. It is slightly shorter than Fairway, but produces similar biomass (Stevens et al. 1983). Ruff was developed from Fairway-type germplasm by the USDA/ARS in cooperation with the Nebraska AES. The new cultivar has a spreading, "broad-bunch" growth habit and is relatively leafy and of short stature. It is recommended for grazing and revegetation of problem sites in the low precipitation zones of the Great Plains.

The USDA/ARS at Logan, Utah has recently developed an improved strain of crested wheatgrass derived from a hybrid between an artificially induced tetraploid of Fairway and natural tetraploid Standard. This promising new grass is presently being released as the cultivar 'Hycrest' in cooperation with the Utah AES and the USDA/SCS. Hycrest has consistently outperformed Nordan and Fairway on several range sites, particularly in terms of vegetative vigor and productivity during the establishment period. The ease with which

this new cultivar is established is particularly noteworthy on semiarid range where stands are usually difficult to attain. In preliminary trials, Hycrest in combination with a herbicide has shown promise for reclaiming areas infested with cheatgrass.

Intermediate Wheatgrass

Intermediate wheatgrass and its pubescent form, pubescent wheatgrass, were introduced from Asia as early as 1907. It is a relatively tall grass with a moderate degree of rhizome development. The species is more productive, but somewhat less drought resistant, than crested wheatgrass. In terms of moisture requirements, its area of adaptation is between smooth brome grass and crested wheatgrass. Because of its large seeds and vigorous seedlings, intermediate wheatgrass is one of the easiest range grasses to establish within its area of adaptation. It matures from one to two weeks later than crested wheatgrass, and therefore provides more and better quality forage during the summer period. The species has been used with success in combination with alfalfa under dryland and irrigation (Asay 1983; Asay and Knowles [1985]).

Several cultivars of intermediate wheatgrass have been released from breeding programs in the U.S. and Canada. 'Greenar', 'Oahe', 'Slate', 'Tegmar', 'Amur', and 'Chief' were released before 1970. All of these are primarily forage types except Tegmar, which is a late-maturing dwarf type well suited for soil stabilization. The most recently released cultivar, 'Clarke', was released in 1980 by Agriculture Canada, Swift Current, Saskatchewan. Although this new cultivar has no visual characters that distinguish it from other cultivars of intermediate wheatgrass, it was selected for improved drought resistance, winter-hardiness, seed yield, seedling establishment, disease resistance, and forage yield. Clarke produced as much or more forage and more seed than Chief or Greenleaf in Canadian trials (Lawrence 1981).

Pubescent wheatgrass differs from intermediate wheatgrass in that it has pubescence on the spikes, seed, and occasionally the leaves. The two grasses are interfertile (Dewey 1978) and considerable hybridization and introgression has likely occurred. Nevertheless, pubescent wheatgrass is considered to be better adapted to droughty, infertile, and saline soils than intermediate wheatgrass (Hafenrichter et al. 1968). Three cultivars, 'Topar', 'Luna', and 'Greenleaf' have been released. Topar and Luna were developed by the USDA/SCS in Washington and New Mexico, respectively, and Greenleaf was developed by Agriculture Canada, Alberta.

Tall Wheatgrass

Tall wheatgrass is a relatively coarse, upright, perennial bunchgrass that is native to the saline meadows and seashores of Europe and Asia Minor (Beetle 1955). It is a late-maturing species and remains green from 3 to 6 weeks longer than most

other wheatgrasses. It is adapted to areas that receive at least 35-40 cm of annual precipitation. Tall wheatgrass is especially noted for its tolerance of salinity and is often productive in areas too saline or alkaline for other useful grasses. This grass has large seeds that are easy to harvest and process, and it has comparatively good seedling vigor. Because of its coarseness and late maturity, tall wheatgrass is often seeded alone, which leads to problems associated with monocultures (Hafenrichter et al. 1968).

The cultivars 'Largo', 'Alkar', 'Jose', 'Orbit', and 'Platte' have been released in North America. Largo and Jose were released by the USDA/ARS and New Mexico AES in 1937 and 1965, respectively; Alkar by the USDA/SCS along with the Washington and Idaho AES in 1951; Platte by USDA/ARS and Nebraska AES; and Orbit by Agriculture Canada at Swift Current, Saskatchewan in 1966. The parentage of many tall wheatgrass cultivars trace to an introduction (PI 98526) from the USSR (Asay and Knowles 1985).

Russian Wildrye

Russian wildrye is a cool-season perennial bunchgrass that has been widely used in western U.S. and Canada. Once established, it has excellent drought and cold tolerance. The species is characterized by dense basal leaves that are high in nutritive value and palatable to grazing animals. Also, its nutritive value during the late summer and fall is better than many other grasses, including crested and intermediate wheatgrass. Poor seedling vigor has been a major limitation of Russian wildrye. Seedlings on semiarid ranges are often unsuccessful, especially when seed beds are poorly prepared or when seeds are planted too deep. The tendency of its seed to shatter soon after maturity also has limited the availability of Russian wildrye seed in commercial channels (Rogler and Schaaf 1963; Smoliak and Johnston 1980b).

The cultivars 'Sawki' and 'Vinall' were released in the 1960's by Agriculture Canada at Swift Current, Saskatchewan and by USDA/ARS at Mandan, North Dakota, respectively. Vinall was selected primarily for increased yield and size of seed (Hanson 1972). Seed size has been positively correlated with seedling vigor in Russian wildrye and other perennial grass species (Asay and Johnson 1983). 'Cabree' was developed by Agriculture Canada at Lethbridge, Alberta (Smoliak 1976). Selection for reduced seed shattering was stressed during its development. 'Swift' was released in 1978 by Agriculture Canada at Swift Current, Saskatchewan. Improved seedling vigor, particularly seedling emergence from deep seedings, was a major selection criterion in this breeding program (Lawrence 1979).

The USDA/ARS at Logan, Utah initiated a breeding program in 1976 to develop improved cultivars of Russian wildrye. Improved seedling vigor under drought stress and plant exploration to provide more genetic resources have been major objectives. Some very promising germplasm has been selected

from an introduction (PI 406468, Bozoisky) recently obtained from the USSR. This new potential cultivar has been significantly more productive and easier to establish on semiarid range sites than Vinall (Asay and Knowles 1985).

Altai Wildrye [Leymus angustus (Trin) Pilger]

Altai is a winter hardy, drought resistant, long-lived perennial that shows potential in western U.S. and Canada. The species is weakly rhizomatous, and its roots can penetrate to a depth of from 3 to 4 m. Altai produces more biomass and has larger seeds and better seedling vigor than Russian wildrye. The forage cures exceptionally well, and its nutritional value is maintained better than in most cool-season grasses. These qualities, along with its erect culms which often protrude through the snow, make Altai a potentially valuable species for extending the grazing season into the late fall and winter (Lawrence 1976). The species is well adapted on the loam and clay soils typical of the prairies of southwestern Canada, and preliminary data indicate that it has comparatively good salinity tolerance (McElgunn and Lawrence 1973).

The cultivar 'Prairieland' was recently released by Agriculture Canada at Swift Current, Saskatchewan. It was selected primarily for improved seed and forage yield, freedom from leaf spot, and good seed quality (Lawrence 1976). The USDA/ARS at Logan, Utah has included Altai in an interspecific hybridization program. Breeding populations have been generated from its hybrids with Great Basin wildrye, L. cinereus (Scribn. & Merr.) A. Löve, and mammoth wildrye, L. giganteus Vahl.

Native Species

Western Wheatgrass [Pascopyrum smithii (Rydb.) Löve]

Western wheatgrass is a rhizomatous, cool-season, perennial grass that is widely distributed in the sagebrush ecosystem and in the central and northern Great Plains. It is an octoploid ($2n=56$) of hybrid origin. Dewey (1975) concluded from his cytological studies that western wheatgrass arose through hybridization between thickspike wheatgrass and beardless wildrye, Leymus triticoides (Buckl.) Pilger, or closely related grasses. It is resistant to drought and is particularly well suited to heavy alkaline soils. It is a poor seed producer and stands are often difficult to establish from seed. Its strong rhizomatous growth habit lends itself to stand establishment with vegetative sprigs, particularly for soil stabilization of relatively small areas (Rogler 1973). Western wheatgrass has been recommended for reclaiming areas disturbed by surface mining or construction, saline seeps, and other problem sites (Scheetz et al. 1981). It provides an excellent source of forage during the early spring. As in many other wheatgrasses, forage quality declines with advancing maturity, although the leaves of western wheatgrass have better curing qualities than crested wheatgrass.

The cultivars 'Barton', 'Rosana', 'Arriba', and 'Flintlock' were made available during the 1970's. Two new cultivars were released in 1983: 'Rodan' by the USDA/ARS at Mandan, North Dakota, in cooperation with USDA/SCS and the North Dakota AES; and 'Walsh' by Agriculture Canada at Lethbridge, Alberta. Rodan is an upland drought resistant type selected for vegetative vigor, forage quality, and rust resistance (Asay and Knowles 1985). Walsh, the first western cultivar released in Canada, was screened for improved forage and seed yield, rhizome development, and freedom from diseases (Smoliak and Johnston 1983).

Thickspike Wheatgrass

This is a widely distributed sod forming perennial valued primarily for soil stabilization on disturbed range sites and other special use applications. As a forage grass, it is most productive during the early summer when the nutritional value of crested wheatgrass is low. Although thickspike is morphologically similar to western wheatgrass, it is more resistant to drought and less productive. It is so closely related to streambank wheatgrass that Dewey (1983) did not recognize them as separate species. Instead, he considered streambank wheatgrass to be a glabrous form of thickspike wheatgrass.

Two cultivars of thickspike wheatgrass ('Critana' and 'Elbee') and one of streambank wheatgrass ('Sodar') have been released. Critana was released in 1971 by the USDA/SCS in cooperation with the Montana AES. It originated from collections made from roadside cuts in north-central Montana and is recommended primarily for revegetation of disturbed range areas and other dry habitats (Stroh et al. 1972). Elbee was developed by Agriculture Canada, Alberta, and released in 1980. The parental materials were native to the plains regions of Alberta and Saskatchewan (Smoliak and Johnson 1980a). Sodar was released in 1954 by the USDA/ARS in cooperation with the Idaho and Washington AES. It was derived from germplasm collected from Grant County, Oregon (Douglas and Ensign 1954).

Bluebunch Wheatgrass

Bluebunch wheatgrass is a cool-season bunchgrass that is widely distributed on the dry plains and hills of the Intermountain Region and Pacific Northwest. Diploid ($2n=14$) and tetraploid ($2n=28$) forms occur; however, the tetraploids are apparently limited in their distribution to eastern Washington and northwest Idaho. Beardless wheatgrass (previously A. inerme) is genomically equivalent to bluebunch wheatgrass but lacks the prominent divergent awns that are characteristic of the latter. The two grasses were included in the same species by Dewey (1983). Bluebunch wheatgrass has excellent nutritional value, and, because of its high palatability, stands are often depleted under heavy grazing pressure. Because of this, it is recommended that grazing of bluebunch wheatgrass be delayed until the late boot stage (Daer and Willard 1981, Hafenrichter et al. 1968, Mueggler 1975).

The cultivar 'Whitmar', a beardless (inermis) type, was released in 1946 by the USDA/SCS in cooperation with the Washington, Idaho, and Oregon AES. It is a diploid ($2n=14$) derived from collections made in the Palouse prairies of Washington (Wolfe and Morrison 1957). 'Secar' was released in 1981 by the USDA/SCS in cooperation with the Washington, Oregon, Idaho, Montana, and Wyoming AES. It is a tetraploid ($2n=28$) selected from germplasm obtained near Lewiston, Idaho. It is an early maturing, drought resistant cultivar adapted to the lower elevations of the Pacific Northwest and similar environments (Morrison and Kelly 1981).

Slender Wheatgrass

Slender wheatgrass, a perennial bunchgrass, has been one of the most widely used native grass species in revegetation programs on the rangelands of western United States and Canada (Rogler 1973). It is relatively good seedling vigor, and, because of its tendency to be short-lived, it is often used to provide forage and ground cover during the interim when more permanent species are becoming established. It has shown potential for reclaiming saline seeps, areas disturbed by surface mining, and other problem sites. Compared to other native wheatgrasses, it produces excellent seed yields, and the seeds are large and generally of good quality. Slender wheatgrass is one of the few self-fertile wheatgrasses and is closely related to bearded wheatgrass, E. subsecundus (Link) A. and D. Löve. The latter is also a native species and is characterized by the presence of awns (Hafenrichter et al. 1968).

Two cultivars are presently included in commercial seed channels. 'Primar' was released in 1946 by the USDA/SCS in cooperation with the Washington, Idaho, and Oregon AES. The parental materials were obtained from natural stands near Beebe, Montana. It is an early cultivar and is resistant to stem and stripe rust and head smut (Hanson 1972). 'Revenue' was developed by the Canada Agricultural Research Station at Saskatoon, Saskatchewan, and released in 1970. It originated from a collection made near Revenue, Saskatchewan. In Canadian trials, it demonstrated better establishment vigor, salinity tolerance, forage quality, and yield of forage and seed than Primar (Crowle 1970; Hanson 1972).

Great Basin Wildrye

Basin wildrye is a long-lived perennial bunchgrass with relatively erect and coarse culms that grow from 90 to 250 cm tall. In the sagebrush ecosystem, it is often found on river banks or water courses, in ravines, and other sites with a water table near the surface. It is adapted to areas with an average annual precipitation of from 25 to more than 40 cm. Its tolerance of alkaline and saline soils compares favorably with that of tall wheatgrass. Basin wildrye has been a valuable winter forage on western rangelands, particularly in Nevada, but overgrazing has depleted many of these native stands. In its area of adaptation, the species is recommended for soil stabilization,

particularly on sites subject to erosion. It also provides a good habitat for wildlife, such as pheasants and waterfowl (Howard 1979).

The cultivar 'Magnar' was released in 1979 by the USDA/SCS in cooperation with the Idaho AES. Parent materials for this cultivar were obtained from the University of Saskatchewan at Saskatoon. The potential of the accession was first noted in the U.S. at the SCS Plant Materials Center, Pullman, Washington by J. L. Schwendiman. The breeding population was subjected to several cycles of selection for general vigor. Magnar was tested as P-5797 prior to its release (Howard 1979).

Indian Ricegrass [Oryzopsis hymenoides (Roem. and Schult.)]

Indian ricegrass is a perennial bunchgrass widely distributed in the sagebrush ecosystem on well aerated, rock or sandy soils. The species is nutritious and palatable to grazing animals. The curing qualities of its forage make it particularly valuable as a source of feed during the fall and winter. Stands of Indian ricegrass are sensitive to heavy grazing pressure during the spring. In its native habitat, the grass is extremely drought tolerant and can be used for revegetation of areas disturbed by surface mining. The seeds of Indian ricegrass, which have a high protein and fat content, contribute to the diet for birds and rodents. The widespread use of the species in range improvement programs has been impeded by seed dormancy problems, although seed treatments have now been developed to improve germination (Booth 1978; McDonald 1976, 1977; Rogler 1960).

The cultivar 'Nezpar' was released in 1978 by the USDA/SCS and the Idaho AES. The parentage of this cultivar was collected from natural stands near Whitebird, Idaho. Selection for low hard-seed content was stressed during its development. The ease of establishment of Nezpar has compared favorably with other Indian ricegrass strains in range trials (Booth 1978).

Interspecific Hybrids

The USDA/ARS at Logan, Utah is actively engaged in a breeding program to develop new cultivars and, in some cases, new species from breeding populations generated through interspecific hybridization. Although problems associated with meiotic irregularity, sterility, and undesirable genetic segregation are formidable obstacles, progress appears to be imminent. The most promising hybrids are:

- quackgrass X bluebunch wheatgrass
- quackgrass X Fairway and Standard crested wheatgrass
- Fairway X Standard crested wheatgrass
- Bluebunch wheatgrass X thickspike wheatgrass

The Fairway X Standard crested wheatgrass hybrid has demonstrated sufficient advantages over existing cultivars to merit release (see crested

wheatgrass, 'Hycrest'). The quackgrass X blue-bunch wheatgrass hybrid (RS hybrid) is also pending release as a cultivar. The initial cross was made by D. R. Dewey in 1962. Over 20 years were required to combine the desired characteristics of the parental species into genetically stable and fertile breeding populations. Two germplasms (RS-1 and RS-2) were released to other plant breeders and plant scientists in 1980 (Asay and Dewey 1981). The chromosome number of the hybrid has stabilized at $2n=42$, and it is as fertile as either of the parental species.

The RS hybrid is best adapted to the 30 to 45 cm precipitation zones. Preliminary observations and data indicate that it responds well to repeated clipping or grazing and it appears to have excellent palatability to grazing animals. The hybrid has exhibited considerable tolerance to salinity. A wide range of genetic variation is present in the population for degree of rhizome development. True-breeding bunch types and those with a moderate degree of vegetative spread have been obtained after three cycles of selection.

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SHRUBS AND FORBS FOR REVEGETATION PLANTINGS IN THE SAGEBRUSH ECOSYSTEM

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ABSTRACT

The sagebrush ecosystem is composed of several distinct plant communities. Productivity of these sites can be enhanced by maintaining and increasing plant diversity. Shrubs and forbs are important components of the ecosystem both in terms of natural occurrence and sustained productivity. An array of plant materials is available for revegetation efforts. More materials are currently being identified and developed to meet management needs. Selection goals are illustrated using big sagebrush (*Artemisia tridentata*) as an example. The importance of land stability and protection is emphasized. Insect and microorganism pests are best managed when plant communities are diverse in species content. Longevity and succession are important but poorly understood in community dynamics. Planting techniques to enhance species and plant life form diversity are discussed.

INTRODUCTION

The sagebrush ecosystem in a broad sense is comprised of several plant communities and habitat types (Küchler 1964; Blaisdell et al. 1982; McArthur 1983b). It is however, unified by including as a dominant form, one or more woody *Artemisia* of the subgenus *Tridentatae* (Beetle 1960; McArthur and Plummer 1978; McArthur et al. 1981). The ecosystem covers large tracts of land in western North America. The ecosystem is one of shrub dominants--probably because stress conditions (aridity, nutrient poor soils, fire, winter cold, short growing seasons, wind) promote the shrubby habitat (McArthur 1984). The sagebrush ecosystem, in its various components, includes differing amounts of grasses and forbs in the vegetational mix. Before disturbances associated with the European culture, mainly caused by domestic grazing animals, there was a higher density of herbaceous plants associated with much of the sagebrush ecosystem (McArthur and Plummer 1978; Young et al. 1979; McArthur 1984). The purpose of this paper, within the context of the sagebrush ecosystem, is to point out the importance of shrubs and forbs, to identify the revegetation potential of shrubs and forbs, to report the selection goals in a plant improvement program, and to comment on pest management and community ecology.

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Some values of shrubs and forbs on rangeland include:

- (1) More productive big game ranges (fig. 1). Forbs provide herbage primarily in the spring and summer (Pederson and Harper 1978, 1984, Tueller 1979) and shrubs in the winter (Cook 1972; Tueller 1979; Welch 1983).
- (2) Deep-rooted shrubs are a more reliable forage source than herbaceous plants, and some shrubs and forbs are capable of symbiotic nitrogen fixation (Klemmedson 1979; Nelson 1983).

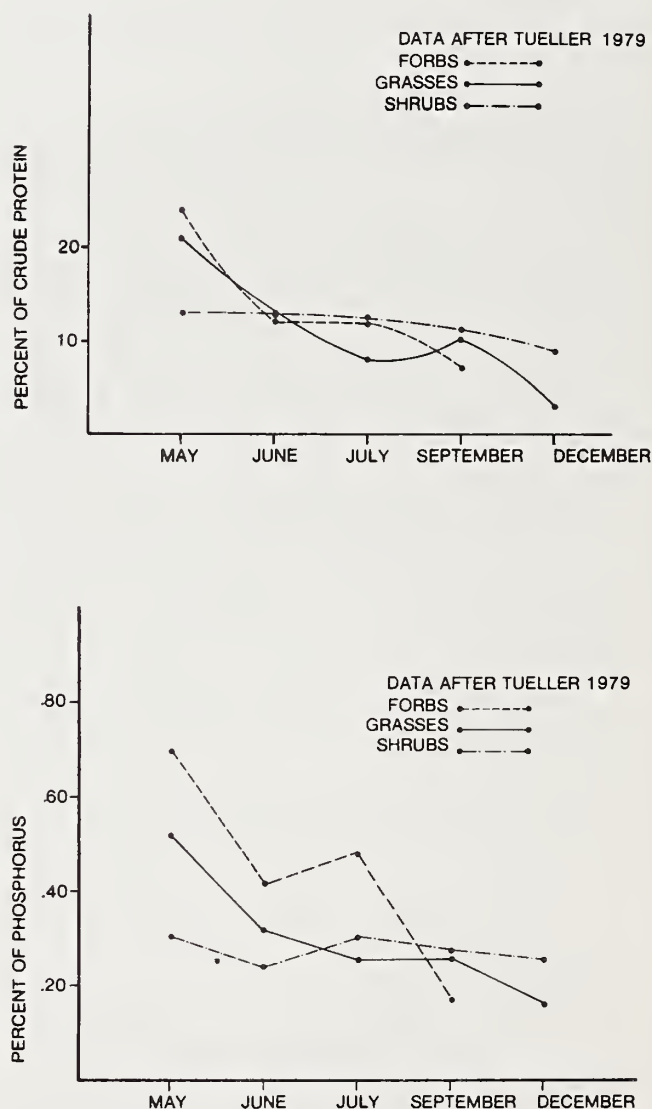


Figure 1.—Seasonal content of protein and phosphorus in forbs, grasses and shrubs.

- (3) Increased plant community diversity permitting support for a wider range of organisms and a longer grazing season (Plummer et al. 1968; Zimmerman 1980; Shaw and Monsen 1983).
- (4) Low-maintenance landscaping for roadsides, rest areas, and campgrounds is enhanced by species that flower at different seasons and produce attractive foliage (Schmutz et al. 1973; Shaw and Monsen 1983).
- (5) Selected species are useful as pioneer species or nurse crops on disturbed sites (Plummer et al. 1968; Shaw and Monsen 1983).
- (6) Some plants may have medicinal or industrial chemical values (McArthur 1983a; Ostler et al. 1984).

There have been many successful seedings in the sagebrush ecosystem (Plummer et al. 1968; Keller 1979; Blaisdell et al. 1982). However, failure is certainly possible depending upon climatic conditions, pest irruptions, and unsuitable planting stock. With the development of improved planting techniques and equipment along with superior planting stock, we believe chances for success for each revegetation project will increase.

PLANT IMPROVEMENT PROGRAM

The West's shrublands have a vast array of naturally evolved and adapted shrub and forb taxa that can be used for revegetation efforts (Plummer et al. 1968; Blauer et al. 1975, 1976; Monsen and Christensen 1975; Plummer 1977; McArthur et al. 1979; McArthur 1984). Much planting stock will continue to come from native plant stands as it has in the past. This stock when properly chosen has several advantages: naturally evolved site adaptation, reoccurring long-term seed availability, and intra population genetic variability. During the last three decades an increasing effort has been made to identify natural populations of shrubs and forbs that meet the above mentioned criteria (Plummer et al. 1968; Monsen and Christensen 1975; Monsen 1976; Welch and McArthur 1979a; Davis 1983; McArthur et al. 1983). Accessions or samples from some populations are being or will be increased by USDA/SCS Plant Materials Centers and by commercial seed growers. Incipient selection and breeding programs are underway to augment and strengthen the availability of the "natural" germplasm stocks. Advanced generation selections are farther away from accomplishment. Work with rangeland legumes has advanced more than other plant categories (Rumbaugh 1983). The status and references for select nonlegume shrubs and forbs are listed in Table 1. Table 1 is not intended to be exhaustive but to list a cross section of plant materials under development. Information on legumes and entry into the pertinent literature can be gained from Rumbaugh (1983).

Table 1.--Status of some potential wildland cultivars, adapted to sagebrush ecosystems

Species	Cultivar	Release date	Reference
<u>Artemisia ludoviciana</u>	Summit and others	1985	Stranathan and Monsen 1984
<u>Artemisia tridentata</u> 1986	Hobble Creek ^{1/}	1986	Welch and McArthur unpublished
<u>Atriplex canescens</u>	Rincon and others	1982	McArthur et al. 1984
<u>Kochia prostrata</u>	Immigrant	1983	Stevens et al. 1985
<u>Ceratoides lanata</u>	Hatch	1985	Monsen and Stevens unpublished
<u>Linum lewisii</u>	Appar	1980	Shaw and Monsen 1983
<u>Penstemon palmeri</u>	Cedar	1985	Stevens and Monsen unpublished
<u>Penstemon strictus</u>	Bandera and other Penstemon spp.	1982	Shaw and Monsen 1983
<u>Purshia tridentata</u>	Lassen and others	1984	Shaw and Monsen in press
<u>Sanguisorba minor</u>	Delar	1979	Shaw and Monsen 1983
<u>Aster</u> spp.	Several possible	--	Shaw and Monsen 1983
<u>Sphaeralcea</u> spp.	Several possible	--	Shaw and Monsen 1983
Legumes	Many	--	Rumbaugh 1983

^{1/}Cultivar name pending, release documentation not completed.

Our own program for development of wildland cultivars has been outlined as follows (Welch et al. In press): A description of management needs (DMN) based on the range use categories, soil stabilization, animal habitat, and esthetics. Evaluation criteria for soil stabilization center around a precise DMN and include root characteristics, potential disease and insect problems, ease and method of establishment, and longevity. Animal habitat needs include forage and cover with an emphasis on nutritional and cover requirements of those animal species designated for special consideration. Depending on the DMNs, candidate accessions are then subjected to a battery of greenhouse, laboratory, and field evaluations. When characteristics need to be combined between or among accessions then hybridization and cycles of selection will be implemented as, for example, we have begun with big sagebrush (*Artemisia tridentata*) (Welch and McArthur 1979a, McArthur and Welch 1982).

SELECTION GOALS

A Case Study

Voigt (1975) stated in the Improved Range Plants Symposium, "Species that are aggressive, productive, and persistent are the ones most likely to benefit from increased forage quality and possibly from increased palatability." Big sagebrush is an aggressive, productive, and persistent range plant that we believe has the potential to increase the nutritive level of big game and domestic livestock winter ranges. The aggressive and persistent nature of big sagebrush is apparent even to the casual observer. It has been estimated that big sagebrush is a dominant species of over 109 million hectares in the western United States (Beetle 1960, McArthur and Plummer 1978). Even during drought when growth of grasses and forbs is almost nonexistent and shrub production is severely limited, big sagebrush still yields substantial amounts of forage (Medin and Anderson 1979, McArthur and Welch 1982). Improvement of forage quality is feasible because big sagebrush has a richly variable germ plasm. What follows is a summary of our progress in developing improved or superior cultivars of big sagebrush for use on big game and domestic livestock ranges.

The first task in our selection program was the establishment of accessions of big sagebrush in uniform gardens. After this was accomplished and the plants reached suitable age, 21 accessions were selected for further study. Tests were then conducted to determine the amount of variation among the 21 accessions for preference (mule deer and domestic sheep), winter crude protein, winter in vitro digestibility, and productivity.

Preference expressed as percent of current year growth utilized for wintering mule deer ranged from 25 percent to 84 percent. The test was run for 4 years and conducted in four different gardens. An accession of big sagebrush from Hobbie Creek, Utah, was the most preferred out of the 21 accessions tested at all gardens and for every year (Welch et al. 1981; Welch and McArthur--in press). For wintering domestic sheep fed a continuous diet of

high quality alfalfa hay, preference ranged from 0 percent to 98 percent (Welch and McArthur--unpublished data). The top three accessions at 90 percent or more utilization of current year growth were Trough Springs, Nevada; Kaibab, Arizona; and Wingate Mesa, Utah. The Hobbie Creek accession was grouped in the upper third. Sheep did not consume any current year's growth of four accessions--all large statured. Sheep were much more selective than mule deer. This difference was probably due to the continuous feeding of the sheep.

Our study of the winter crude protein content of the 21 accessions showed that some accessions contained significantly higher levels of crude protein than others (Welch and McArthur 1979b). The mean crude protein content for all plants was 12.4 percent and the range was 8.8 percent (8.3 to 17.1 percent). Accessional range was 6 percent (10 to 16 percent). Those accessions containing the highest crude protein were, unfortunately, the same that were not eaten by domestic sheep and least preferred by wintering mule deer. Breeding these accessions with those that are the most preferred by domestic sheep could result in a cultivar superior to both parents. As a winter forage big sagebrush ranks high in crude protein (Welch and McArthur 1979b).

For winter in vitro digestibility, an indicator of energy content, some accessions were more readily digested than others (Welch and Pederson 1981). In vitro digestion ranged from 44.6 percent of dry matter digested to 64.8 percent. Again, the accessions not eaten by wintering domestic sheep and least preferred by mule deer were the ones having the highest digestibility. These accessions are the "ones most likely to benefit from increased palatability" (Voigt 1975).

Our productivity studies showed that some accessions grown on three different uniform gardens were more productive than others (McArthur and Welch 1982; Welch and McArthur, unpublished data). Productivity expressed as centimeters of current year's growth of leaders varied from 5.8 cm to 21.4 cm. The most productive accessions were not eaten by wintering domestic sheep.

Recent studies have demonstrated that some accessions of big sagebrush are more resistant to snow mold than others (Nelson--unpublished data). Snow mold is a fungal disease of big sagebrush and other plants that develops on plants under snow cover and can kill a plant after 2 to 4 years. Other disease problems of big sagebrush are being studied.

We are continuing our studies on adaptation and have initiated controlled environment (greenhouse) drought tolerance evaluations.

Our use of the data described above is in two directions. First we are gathering the needed data to release the Hobbie Creek accession as a winter forage for mule deer and domestic sheep (table 1). We are evaluating other accessions of big sagebrush for release in areas where the Hobbie Creek accession is not adaptable. Our second direction is attempting to increase the preference or "palatability" of accessions that are high in crude protein, productivity, and in vitro digestion.

Crosses have been made and confirmed hybrids are to be evaluated.

Similar studies have been initiated on bitterbrush (see several articles in Tiedemann and Johnson 1983), fourwing saltbush (McArthur et al. 1983, 1984; and articles in Tiedemann et al. 1984), and other shrubs (Ferguson 1983; McArthur 1983a; Stutz 1983) and forbs (Rumbaugh 1983; Shaw and Monsen 1983).

Land Stability and Protection

Components of the sagebrush ecosystem usually are not high water-yielding watersheds (Hutchison 1965). However, sagebrush occupies extensive wildlands, often existing on steep, erosive soils. The arid regions of the sagebrush ecosystem normally provide an open sparse vegetal cover. Some stands of Wyoming big sagebrush naturally have up to 25 percent bare ground (Winward 1980). Disturbances caused by fires or grazing usually reduce ground cover. Intense summer storms and high winds frequently cause extensive flooding and soil losses from disturbed sites. Undisturbed sites also may yield high amounts of sediment (Sturges 1975). Areas subjected to soil losses become increasingly difficult to stabilize. Light-textured soils that are exposed through loss of the vegetal cover frequently become so unstable that the native species are no longer adapted to the harsh sites.

Planting or treatment of exposed sites must be instigated soon after disturbances are created to minimize soil erosion. Plantings are also required to prevent the invasion of annual weeds that do not furnish satisfactory ground cover.

Extensive stream degradation has occurred in the riparian communities that traverse the sagebrush ecosystem ranges (Meehan and Platts 1978). To control and improve the riparian habitats, the entire watersheds must be stabilized. Consequently, management of arid communities associated with the sagebrush ranges is essential to stabilize streams and control runoff. It is essential that a plant selection program takes into account the necessity of providing rapid and effective soil binding.

INSECTS, DISEASES, AND MICROORGANISMS

Integrated pest management calls for land managers to make control and other management decisions regarding the "pests". Such decisions can be difficult to make and equally difficult to carry out. Disease and damage vectors, principally microorganisms and insects, like their host plant species, include both harmful and beneficial members--often depending on one's perspective. Big sagebrush, for example, is a fine mule deer winter forage, but thick, closed stands are unacceptable to virtually all land managers (McArthur and Plummer 1978). Viewed at a more generic level, insects and microorganisms provide both benefit and harm to the health and management of sagebrush ecosystem ranges.

Beneficial insects are essential to the effective seed production of many wildland shrubs and forbs

and to the control of damaging insects (Haws 1982; McArthur 1984). Microorganisms are important in the nutrient uptake of plants by involvement in symbiotic nitrogen fixation (Klemmedson 1979; Nelson 1983; Rumbaugh 1983) and mycorrhizal function (Moorman and Reeves 1979; Allen 1984). Despite the positive values of insects and microorganisms, most management concerns are directed to problems these organisms cause. We mention only a few such problems to draw attention to their scope and impact on plant materials programs.

Most pest problems are more severe when plant species are dense. For example, the lygus bug, Lygus desertinus, reaches epidemic proportions in seed plantations of forage kochia (Kochia prostrata) but is of little consequence in plants found in scattered field plantings (Moore et al. 1982). A similar condition exists between a case-bearing bagworm defoliator, Coleophora atriplicivora, and Atriplex species including fourwing saltbush (Atriplex canescens). Dense seeded populations (Meadows et al. 1984) and seed orchards (Moore and Stevens 1984) can be devastated by the case bearer, but scattered plants receive little harm despite presence of the insect. There are, of course, many other insect problems that occur on plants in the sagebrush ecosystem. For further information we suggest the following references: Furniss 1972; Furniss and Barr 1975; Haws 1982. Plant diseases are also usually more severe in closed species stands. Krebill (1972) reviewed the diseases on western shrubs. David L. Nelson, of our laboratory, and colleagues are updating the list of known diseases. We make the point that wildland shrub and forb diseases are poorly known. Vascular wilt of shrubs in plantations and in natural populations is a problem with both big sagebrush (Nelson and Krebill 1981) and fourwing saltbush (Nelson and Welch 1984). The fungal genera Fusarium, Rhizoctonia, Sclerotinia, Alternaria, and Gliocladium are involved in these vascular wilt diseases. Snowmold disease of big sagebrush (Nelson and Sturges 1982), mentioned above in the case study of selection goals, is another problem.

We believe that species diversity is the best defense against insect pests and diseases. Mixed species stands tend to inhibit and slow disease and insect irruptions.

LONGEVITY AND SUCCESSION

Arid rangelands dominated by big sagebrush, particularly Wyoming big sagebrush (Artemisia tridentata ssp. wyomingensis) usually lack a diversified array of understory species. Relatively few broadleaf herbs are encountered in the sagebrush types compared with other major plant communities (Winward 1980). Density of annual forbs fluctuates seasonally influenced by annual precipitation.

In many areas the presence of perennial grasses has been reduced by heavy grazing and fires (Pickford 1932). Native ranges have historically been subjected to wildfires (Burkhardt and Tisdale 1976).

The influence of burning depends upon the intensity of the fire, timing, and species of plants involved (Wright and Klemmedson 1965). Fires have been used to regulate the balance between shrub and grass species (Pechanec et al. 1954). In many instances continuous and heavy grazing has selectively eliminated native perennial grasses (Young et al. 1972, 1979). As understory species have been reduced in density, annual weeds, particularly cheatgrass brome (*Bromus tectorum*), have invaded (Piemeisel 1951). The competitive influence of cheatgrass brome interferes with the re-establishment of slower developing native perennials. In addition, seeded species are also difficult to establish without removal of the annual understory. Consequently, natural establishment and secondary successional changes in plant composition are dictated by the presence of the introduced annual (Young and Evans 1978). Reestablishment of native or introduced species can only occur following regulatory treatments of the annual grass.

Planting or seeding introduced grasses and forbs in the sagebrush-cheatgrass ranges has usually been more successful than planting native forbs (Hull and Holmgren 1964). Most introduced cultivars have vigorous seedlings, compete well with annuals, and persist under heavy grazing and widely fluctuating climatic conditions (Plummer et al. 1968). In contrast, most native perennial grasses lack seedling vigor, which restricts natural and artificial seeding (Vallentine 1971).

The combination of plants that are seeded in a disturbed sagebrush community can be used to determine species composition, density, and the subsequent establishment of other plants. Most introduced grasses are persistent and long-lived. Many planted species may persist for over 40 years (table 2). Certain introduced wheatgrasses develop dominant stands and can be seeded to control the entry of other plants (Asay 1982). Under semiarid conditions where a limited number of herbs occur, introduced grasses may control the establishment of other plants.

Studies have not determined the compatibility and successional changes that may occur when combinations of native and introduced herbs are planted together. Bluebunch wheatgrass (*Agropyron spicatum*) and Idaho fescue (*Festuca idahoensis*) both persist and grow favorably when planted with introduced grasses. However, if mixed plantings are not properly managed, these two may not persist. Certain species require a long period to establish, but tend to gain in plant density 10-15 years after seeding. Seeding of broadleaf forbs, particularly palatable forage species, may create fluctuation in species density and diversity. Adding range-type varieties of alfalfa (*Medicago sativa*) and small burnet (*Sanguisorba minor*) influences the grazing preference of foraging animals. These species attract grazing and if seeded in limited amounts may be seriously weakened by heavy use. Their losses allow for the entry of other plants. Land managers have attempted to improve species diversity and herbage production by adding legumes and other forbs to range seedings. Failure to plant enough seed to attain a sufficient density of broadleaf herbs can result in a rapid decline of the few established plants.

Broadleaf herbs may, in some instances, enhance the performance of associated species. Forage yields and quality have been increased by adding legumes to range seedings (Rumbaugh et al. 1982). Monsen and Shaw (1983a) reported that when grass-legume mixtures are planted, the vigor, density, and yield of the seeded grasses is improved by the presence of the legumes. Monsen and Plummer (1978) have also reported that some broadleaf herbs respond as nurse crops, promoting the establishment of other species. Hironaka (personal communication) postulates that grasses including bottlebrush squirrel-tail (*Sitanion hystrix*) may be used to control cheatgrass brome and enhance the establishment of more persistent perennials. In the sagebrush communities, broadleaf herbs are important forage species. Sites subjected to heavy grazing usually have lost the diverse assembly of herbs. Conse-

Table 2.--Longevity of grasses--Elk Creek Study Site, Idaho

Seeded species	Planting date	Relative ratings ^{1/} - dates				
		1940	1944	1948	1972	1978
<i>Agropyron cristatum</i>	1939	9	10	9	10	6
<i>Agropyron elongatum</i>	1939	10	9	10	8	3
<i>Agropyron intermedium</i>	1941		9	10	10	9
<i>Agropyron sibiricum</i>	1940		10	9	6	6
<i>Agropyron spicatum</i>	1939	9	10	10	--	8
<i>Agropyron spicatum</i>	1939	9	10	10	10	10
<i>Agropyron trichophorum</i>	1939	10	10	10	10	10
<i>Bromus inermis</i>	1939	9	10	7	8	9
<i>Dactylis glomerata</i>	1942		10	8	7	0
<i>Elymus canadensis</i>	1939	9	9	0	0	0
<i>Festuca idahoensis</i>	1939	9	4	0	0	0
<i>Festuca ovina sulcata</i>	1942		10	9	9	9
<i>Poa compressa</i>	1939	8	7	6	4	4
<i>Sitanion hystrix</i>	1939	8	9	7	2	0
<i>Stipa lettermani</i>	1940		4	1	0	0

^{1/} Relative ratings; 10 = full stand.

quently, native broadleaf herbs often fail to invade protected areas due to lack of a seed source. Many disturbed sagebrush lands must be seeded with broadleaf herbs if these species are to be reestablished.

Both introduced and native species exhibit well-defined trends in growth performance, period of establishment, longevity, and persistence. Species with different growth habits are often planted together to complement growth responses. For example, plantings often include yellow sweetclover (*Melilotus officinalis*), a biennial, with perennial grasses. The legume grows and attains a mature stature in one season. The slower developing grasses reach maturity usually in 2 years. At this time the forb declines in importance. The composition of the seeded perennial grasses is ensured by the initial presence of the biennial. The seeded forb controls the early invasion of weedy species, yet is compatible with the seeded grasses.

Long-term changes can also be regulated by utilizing species with different growth characteristics. When seeded in mountain big sagebrush communities, mountain brome (*Bromus carinatus*) established quickly. The dominating presence of this sod-former may initially restrict the establishment of other seeded herbs. However, mountain brome usually weakens and may be replaced by invading perennials. The litter and seedbed conditions provided by the brome enhance seedling establishment of other plants. Consequently, native species may not reestablish for 10-20 years after sites are initially planted.

Growth habit and plant stature are also significant factors that may influence community structure. Differences in growth habit may not be recognized as important traits that control species diversity, yet they are contributing factors. Some closely related grasses that are similar in areas of adaptation, but differ in structure, exist with somewhat different species. The growth habits of standard (*Agropyron desertorum*) and fairway wheatgrass (*Agropyron cristatum*) are comparative examples. Fairway is somewhat less drought tolerant than standard. Yet, when planted in the arid big sagebrush communities, fairway may better restrict the entry of other species as it develops a weak but competitive sod. In contrast, standard often forms distinct clumps that are widely spaced. During years of above average precipitation, other species may invade the open stands of standard wheatgrass. Differences in the sod density among ecotypes of intermediate wheatgrass also have dramatic effects upon the invasion of other plants. Intermediate wheatgrass is usually considered to be an aggressive perennial and develops a dense sod. The cultivar 'Amur' forms a more open sod than does 'Tegmar,' 'Oahe,' or 'Greenar.' When seeded on rangeland sites, native species invade 'Amur' plantings. The other cultivars are much more competitive, limit the establishment of other species for an indefinite period, and create extensive monocultures.

Seeding rates and row spacings can also be employed to determine plant composition and species diversity. Usually, seeding more than 15 pounds of seed per acre on big sagebrush ranges has little effect. Planting sites are capable of supporting only a certain number of seedlings and further saturation of the site will not produce many more plants. Not all plants have mutually compatible seedlings. Consequently, adjusting the seeding rate is often necessary to achieve a desirable stand. Improvement of seedbed conditions to reduce competition (Beardall and Sylvester 1976), enhance soil microflora (Rumbaugh and Johnson 1984), and provide adequate moisture can significantly improve seedling establishment. Weak stands allow weeds to establish, which can delay the recovery of a native or seeded community.

Seeding rates and row spacing have pronounced influence upon the survival of shrub seedlings. Shrub seedlings usually grow rather slowly, and can be suppressed by more rapid developing grasses. If mixed grass and shrub stands are desired, seeds must be planted in separate rows to reduce competition the first 1 or 2 years (Monsen and Shaw 1983b).

Shrubs are normally slow to invade established stands of grass. However, sagebrush is able to gain entry into native grass stands following fire or other disturbance (Daubenmire 1975). Rangelands seeded to adaptive introduced grasses can better restrict shrub establishment if the sites are properly managed. Woodward et al. (1984) report that soils high in monovalent cations and deficient in divalent cations favor shrubs, whereas grasses respond to the opposite situation. Regardless of management techniques, grasses may not persist on soils low in bivalent cations.

Management is perhaps the most central factor that affects community structure and successional trends. Poorly controlled grazing often eliminates highly desirable forage species and allows weeds to gain dominance.

Fires have been instrumental in maintaining seral communities (Young and Evans 1979; Wright et al. 1979; Blaisdell et al. 1982). The suppression of wildfires and the misuse of controlled burns has diminished the number of certain species. Young (1983) described the capabilities of various species to recover and persist following burning and the conditions that influence plant survival. Most herbaceous species adapted to the sagebrush communities respond positively to natural fires. Community structure may be regulated with burning.

Most introduced grasses selected and recommended for seeding in the sagebrush types develop rapidly and form a competitive stand (Hafenrichter et al. 1968). Some plantings persist as extensive monocultures, yet almost all sites are subjected to change. The extreme variability in annual moisture received in these semiarid rangelands can change plant density and species composition. Bottlebrush squirreltail and Sandberg bluegrass (*Poa secunda*) are capable of increasing and decreasing significantly from year to year. Most introduced species are able to remain as dominant plants

within the sagebrush community. The introduced species are able to persist under heavy grazing and other intensive use. Consequently, deteriorated sagebrush ranges have been improved by seeding with introduced herbs.

PLANTING TECHNIQUES FOR DIVERSE SEEDINGS

Sagebrush rangelands usually are planted after a natural disturbance or after planned eradication of the sagebrush. Many of the companies that supply planting stock are listed in the six references: Crofts and McKell (1977), Brown et al. (1980), Slayback (1980), Everett (1981), Long (1981), and USDA Soil Conservation Service (1982). Wildland seedings have not proven to be successful unless the competitive stands of sagebrush are removed or reduced in density (Pechanec et al. 1965; Jordan 1981). If cheatgrass brome or other annuals have invaded the sites, control measures must also be employed to reduce the competitive effects of the annuals (Evans 1961).

Plummer et al. (1968) described ten major steps that must be considered in wildland seeding. These practices include the removal and control of competition and the conservation of moisture through preparation of an adequate seedbed. It is critical that proper site preparation practices be used in seeding arid and semiarid ranges. Water conservation and protection of the new seedlings is vital to stand establishment (Jordan 1983). Various methods of planting are acceptable if weed control, water conservation, and proper seed placement are achieved.

Drill seeding is normally successful; however, broadcast seeding is a satisfactory method of planting irregular and inaccessible sites (Plummer et al. 1968). It is perhaps the cheapest means of disseminating seed. To assure success, seed must be incorporated into the soil (Harper et al. 1965). Seeded sites may require mechanical coverage using a drag, anchor chain, or pipe harrow. Small, smooth seeds will usually be covered if planted on a rough surface. Chaffy seeds or seeds with appendages usually must be incorporated into the soil by mechanical methods of planting.

Broadcast seeding has some advantages over drill seeding under certain circumstances. If soils tend to crust, broadcast seeding is preferred. Mechanical tillage or seeding induces crusting. Broadcast seeding followed by chaining or harrowing causes the seed to be planted at different depths. Seeds do not all germinate at the same time, which often favors establishment.

Drill seeding can be accomplished using a number of range-type drills. Various drills have been designed to operate on rocky adverse sites. Most drills have independent seeding units that can operate over debris and rough terrain (U.S. Department of Agriculture and U.S. Department of Interior 1965). Recent innovations in the seedbox and in furrower openers now allow planting trashy seeds with conventional drills (Wiedemann 1975, 1982). Additional seedboxes have also been added

to existing drills, thus seed of an individual species can be placed in a separate drill row (Wiedemann et al. 1979; Wiedemann 1983).

Heavy-duty furrower openers have been constructed for the Rangeland drill and can be used to remove existing competition. Planting depths cannot always be satisfactorily incremented with this machine, and seeds of different size cannot always be adequately placed in the soil. Small seeds often are planted too deep. However, if properly operated, drill seeding is a satisfactory technique.

Interseeding or intertransplanting is a practice used to establish desirable plants in an existing stand of vegetation. Usually small strips are created by removing existing vegetation via mechanical or chemical means and by seeding into the clearing (Stevens 1979, 1980). The practice can be used to increase species diversity without complete elimination of the existing vegetation. Either seed or transplant stock can be planted in the clearings (Shaw 1981; Stevens 1981).

Combination plantings usually increase diversity. When shrubs or other slow-developing species are planted with herbaceous plants, the species must be separately placed to reduce competition. Separate plantings have best been achieved by seeding the herbs with a conventional drill and the shrubs with the "Hansen Seed Dribbler" (Plummer et al. 1968). Other single row seeders have also been used to plant shrubs or other selected species in separate rows (Monsen and Shaw 1983b). Combined plantings are effective and efficient measures.

Hand broadcast or mechanical seeding can be used to seed specific sites or spots. Extensive areas cannot be effectively treated by hand planting, yet different methods of plantings are often necessary. Problem sites or high-producing areas should be selectively planted. Often separate areas are quite large and well defined and can be planted in a different manner than adjacent sites. Select planting often provides a number of plants to naturally reseed surrounding areas. In addition, spot planting is a means of conserving expensive seed for planting the most favorable sites (Shaw 1981).

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ABSTRACT

Sagebrush-grass ecosystems are somewhat unusual in their response to grazing. In general, sagebrush ranges in fair or better condition seem to be extremely susceptible to deterioration caused by improper grazing during the growing season, i.e., grazing too early, too heavily, or at the same time each year. Simple grazing systems involving uncomplicated rotation or deferment from grazing probably are as effective as more complicated, specialized grazing systems to avoid damage and possibly to get improvement. In contrast, sagebrush-grass ranges in poor condition respond quite slowly or not at all to the most favorable grazing management systems or even complete rest from grazing. Thus, discussion of grazing systems in the context of IPM seems appropriate. Some form of IPM (i.e., reduction or control of sagebrush, along with or followed by proper grazing management as discussed above) is needed to improve most depleted sagebrush-grass ranges. If the native perennial understory has been eliminated, seeding of the range will also be required.

If you do remove sagebrush and plant adapted grasses, the management must be changed drastically to take advantage of these improvements. This is often ignored by managers, especially on public rangelands. Grazing systems designed to make the best use of and maintain seeded species usually are completely different from those needed to maintain or improve native sagebrush-grass ranges. Some specialized grazing systems, such as short duration grazing, might work quite well on some seeded ranges. Other systems, such as rest-rotation, have features that are not well adapted for use on seeded ranges.

INTRODUCTION

Discussions in the literature on the effects of different grazing systems on herbage yield, range condition, and livestock performance on sagebrush-grass rangelands are often contradictory. Often a grazing system has been applied on sagebrush-grass rangelands because it worked in other types, because an agency is committed to using the system, or for no reason at all. For example, in the 1960's and 1970's, "rest-rotation" became the system for Forest Service and BLM allotments throughout the West. This system, originally designed for an Idaho fescue (*Festuca idahoensis*) bunchgrass-type range, has been widely extended into other vegetation types with varying success.

The grazing system or method for the 1980's seems to be "short duration grazing," or the "Savory grazing method" (Savory 1978, Savory and Parsons 1980). In the United States, most applications of

this have been in the Southwest, but both research and on-the-ground applications are increasing throughout the West.

A main problem with much of the research on grazing systems and their application has been that other principles of good range management were not considered or measured. In actual practice all or some of the following management tools usually are applied in addition to the regulation of grazing; fencing, water development, seeding, brush control, fertilizing, salt distribution, and intensified animal husbandry to improve distribution. This is the area where Integrated Pest Management (IPM) and grazing management must be considered and discussed together.

What is a grazing system? A glossary published by the Society for Range Management (1974) contains these definitions:

GRAZING MANAGEMENT: The manipulation of live-stock grazing to accomplish a desired result.

GRAZING SYSTEM: A specialization of grazing management which defines systematically recurring periods of grazing and deferment for two or more pastures or management units.

Vallentine (1979) presented two major misconceptions about grazing systems: (1) a universal grazing system exists; and (2) specialized grazing systems are the long-awaited panacea that will permit ignoring the other principles of grazing management.

HISTORY OF LIVESTOCK USE IN THE GREAT BASIN

The grasslands of the Great Plains evolved under grazing, often quite heavy grazing, by bison, pronghorn, and other ungulates. These grasslands are quite resistant to damage caused by grazing by domestic livestock. In contrast, much of the sagebrush-grass ecosystem had not been subjected to any great grazing pressure since the Pleistocene (Young et al. 1976). When large numbers of livestock were introduced, the understory plants were not able to withstand the grazing pressure. Most of these plants are cool season species, and the growing season is quite short. Heavy grazing, especially during the spring growing season, caused rapid deterioration of the understory species, and the sagebrush, being rather opportunistic, increased.

The dates when domestic livestock were introduced in any numbers in the Great Basin sagebrush country varied somewhat with location. Many travellers went through vast areas of sagebrush on the Oregon and California trails starting in the 1840's, but their impact did not extend very far from the established trail routes. The first permanent settlement of any size came with the Mormon settlement of Utah in 1847. The discovery of the Comstock lode in California in 1859 started the mining boom in Nevada. The resulting demand for food and other livestock products caused the sagebrush rangelands to be stocked heavily rather quickly, resulting in early and rapid depletion of the sagebrush ranges. Young et al. (1979) stated that:

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"The sudden introduction of concentrations of large herbivores into an environment that had not been heavily grazed since the close of the Pleistocene had spectacular results. After 25 years of expansive livestock production, the cream of the potential of the sagebrush/grasslands for supporting cattle was gone. Undoubtedly many ranges distant from water remained in pristine condition, just as such examples can be found today; for most of the sagebrush/grasslands, however, the native perennial grasses were greatly reduced. The inherent potential of the native perennial grasses left them extremely susceptible to intensive, continuous grazing pressure. If the sagebrush/grasslands had been true grasslands, the perennial grasses could have returned with relaxed grazing pressure. However, the shrub portion of the community proved remarkably resistant to grazing... Shrubs, especially big sagebrush, increased in density as perennial grasses were removed from communities."

Accounts by a number of scientists documented the disastrous effects of heavy and continuous grazing on the sagebrush-grass rangelands. Kennedy and Doten (1901) and Kennedy (1903) described the degraded rangelands in Nevada. At this time, the perennial forage species had been severely depleted or destroyed but only some of the introduced annual species, mainly Russian thistle (*Salsola kali* ssp., tenuiflora) and tumble mustard (*Sisymbrium* spp.), had been introduced in any quantity. According to Stewart and Hull (1949), cheatgrass (downy brome) (*Bromus tectorum*) was introduced into southern Idaho in 1900. Halogeton (*Halogeton glomeratus*), medusahead (*Taeniatherum asperum*), and other common alien species were not a problem in the early years of the century.

Griffiths (1902) described the depletion of the sagebrush and other range types in Oregon. Senate Document 199 "The Western Range" (U.S. Senate 1936) outlined the serious depletion of much of the western rangeland including all of the sagebrush-grass ecosystem.

EFFECTS OF GRAZING ON SAGEBRUSH RANGES IN FAIR OR BETTER CONDITION

For purposes of this discussion, ranges in fair or better condition are considered those with an open to moderate stand of sagebrush with the major perennial herbaceous species still present in the understory, even though the latter might be low in vigor or few in numbers.

Spring Grazing

Early research studies in Idaho (Craddock and Forsling 1938), Utah (Hanson and Stoddart 1940), Nevada (Fleming, 1922) and other places clearly proved the susceptibility of sagebrush-grass ranges to deterioration caused by improper spring grazing; i.e., grazing too heavily, too early in the spring, or by grazing at the same time each year. What are proper management systems for sagebrush ranges grazed in the spring? The literature is not at all clear.

In Idaho, Pechanec and Stewart (1949) recommended both rotation grazing and spring deferment for threetip and mountain big sagebrush habitat types grazed by sheep in spring and fall. They concluded that rotating grazing among different units in the spring, but in a different sequence each year, was an effective method of maintaining range in satisfactory condition or improving range in unsatisfactory condition.

In southeastern Oregon on sagebrush-grass range dominated by big sagebrush, bluebunch wheatgrass, Idaho fescue, and Sandberg bluegrass, Hyder and Sawyer (1951) concluded that season-long grazing was more favorable to both cattle and vegetation, mainly because the rotation system resulted in serious overgrazing during the first period of use.

On a sagebrush-wheatgrass range in southern Wyoming, Gibbens and Fisser (1975) compared four-pasture rest-rotation, two-pasture deferred, and one-pasture continuous systems grazed by cattle from spring until winter. Following a 25 percent reduction in permitted grazing at the beginning of the study, all units improved in range conditions without apparent effect on wildlife populations. Apparently stocking rates had not put enough stress on vegetation to cause differences, because range conditions improved under all treatments.

Other studies can be cited to agree with any of these three different conclusions.

Summer Grazing

Studies of effects of summer grazing have been from two different situations--low elevation ranges where the herbaceous understory species are essentially dormant during the summer due to lack of soil moisture, and higher elevation ranges where soil moisture is adequate for continued growth either in early summer or all summer.

On lower elevation sagebrush-grass range in southeastern Idaho, Harniss and Wright (1982), after defining moderate grazing in the spring as 16 sheep days per acre, concluded that sheep can graze in the summer at the rate of about 36 sheep days per acre without apparent damage to the vegetation. Grazing was with ewes whose lambs had been weaned, because the ewes cannot maintain milk production on the dry summer conditions in the lower sagebrush areas. The system used was continuous grazing in either early summer (July) or late summer (late August). There were no indications from this study that any more sophisticated grazing system would be required for summer grazing. However, some discussion was given about using an optimal mix of spring, summer, and fall grazing to maintain or improve productivity of sagebrush-grass ranges.

On higher elevation sagebrush-grass areas used as summer range, the effects of different management systems do not seem to be significantly different--again, as long as the grazing rate is not too heavy and the forage plants have a chance to make a considerable amount of growth before grazing starts.

In the Big Horn National Forest in Wyoming, on Idaho fescue rangeland with some inclusions of

mountain big sagebrush, rotation grazing was no better than season-long grazing for maintaining the vegetation (Smith et al. 1967). Other studies, generally with conflicting results, will be summarized in a later section dealing specifically with rest-rotation grazing.

Fall or Winter Grazing

Grazing in fall and winter generally is considered to have little effect on condition of sagebrush-grass ranges. The herbaceous plants are dormant and may be covered by snow. Unless stocking density is so high that trampling causes physical damage to the herbaceous plants, the effect is minimal. Thus, no particular grazing system should be needed or be of any particular advantage in preventing damage to sagebrush-grass ranges grazed in the fall or winter. However, heavy late fall grazing by sheep has been shown to be a potential tool for improving sagebrush-grass ranges. At the U.S. Sheep Experiment Station, Mueggler (1950) found that an area in good condition was maintained by heavy sheep grazing in the fall, but that much lighter spring use caused serious deterioration of threetip sagebrush rangeland. Laycock (1967) found that both heavy fall grazing and complete protection improved poor condition range. Over a 14-year period, the fall grazing reduced threetip sagebrush by 22 percent and increased production of grasses and forbs by 36 percent. Grazing rate was 60 sheep days per acre on a range where 16 sheep days per acre in the spring is considered proper use. The heavy fall grazing treatment was as good as, and by some criteria better than, complete protection in the improvement of the range. Studies by Frischknecht and Harris (1973) produced much the same results with heavy fall sheep grazing in Utah on seeded rangelands being invaded by big sagebrush. The reasons for improvement of the range by heavy fall grazing apparently are; (1) the grasses and forbs are dormant during the fall so grazing them causes no damage, (2) sheep utilize some sagebrush (the amount depending upon snow depth), which may cause some damage to the shrubs, and (3) the grasses and forbs, which are vigorous from the spring deferment, are able to increase at the expense of the sagebrush.

Other browsing animals might be useful in reducing sagebrush by heavy grazing in the fall. Goats have been used to control oak, chaparral species, and other shrubs, and might be useful in the sagebrush type. Introduction of other animals that can utilize sagebrush to produce meat or fiber is another management alternative.

Martin (1967) noted that many of the large herbivores, such as camels, ground sloths, and mammoths, that became extinct in North America during the late Pleistocene, were browsers and may have been a factor in keeping shrub density low in many different shrub types. He theorized that these browsing niches are now empty, resulting in increases in the range and density of many shrubs, especially in the southwestern United States. If animals could be found which could subsist largely on sagebrush and produce salable products, some of the problems of management in areas where sagebrush is too thick might be solved. Some possibilities are domestic

goats and some of the large African browsing game animals, such as the eland.

EFFECTS OF GRAZING ON SAGEBRUSH RANGES IN POOR CONDITION

Sagebrush-grass rangeland in poor range condition usually is characterized by an extremely dense stand of sagebrush with an impoverished understory of remnant perennial species or annuals. In extreme situations, where frequency of fire has been a factor in addition to heavy grazing, the sagebrush may be gone and the site dominated by cheatgrass brome or other annuals. Season of grazing has little effect on these ranges.

Where a remnant stand of perennial herbaceous species remains under a thick sagebrush stand, only a slight amount of improvement in range condition and forage production can be expected with spring deferment or even complete removal of grazing. Once the sagebrush dominates the site, the grasses and forbs usually cannot regain control unless something occurs to reduce the competition from the sagebrush. This can be either deliberate reduction by man or natural reduction caused by insects, disease, rodents, or fire.

Numerous examples exist where the sagebrush maintains control of the site for very long periods, even in the absence of grazing. Tisdale and Hironaka (1981) state, "recovery from a depleted condition can occur, but tends to be very slow when a dense cover of sagebrush is present." Sanders and Voth (1983) found no improvement in 3 exclosures in a sagebrush community in southwestern Idaho after a 46-year period with no grazing. West et al. (1984) found no significant changes in a sagebrush type in west central Utah after 14 years of livestock exclusion, and concluded that the present sagebrush-dominated community probably is successional stable.

An exception to the continued dominance of sagebrush with improved management was reported by Cooper (1953) in northwestern Wyoming. After only 8 years of deferment from spring grazing and reduction in stocking rate, sagebrush was reduced from 55 to 10 percent composition and grasses increased from 20 to 75 percent composition. This is the only example found in the literature of such a drastic improvement in sagebrush range caused by management. Ellison (1960) theorized that the site was one on which sagebrush was not originally a part of the community but had invaded following overuse. Then, with the change in management, the grasses were able to again dominate the site. Frischknecht (1979) suggested that some unknown biological agent (insect or rodent) might have caused the rapid reduction in the sagebrush.

In situations where grazing has completely eliminated the perennial understory herbaceous species, no grazing management system or change in season of use can improve the range. Where there is an understory of annuals under a dense stand of sagebrush, some seasonal use can be made by livestock when the annuals, especially cheatgrass brome, are green. In many situations, however, the sagebrush is so thick that it hampers movement and distribution of livestock so that effective use of even

this ephemeral forage crop of annuals cannot be made. Grazing use of the annuals is strictly a marginal operation with no hope of improved condition. Restoration of such rangeland to a productive state requires removal of the sagebrush and planting of adapted grasses, legumes, or other forbs. This will be discussed in more detail below.

There are large areas of southern Idaho where fire, coupled with overgrazing, has converted very large areas of former sagebrush-grass rangeland to almost pure stands of cheatgrass brome. In other areas farther west, medusahead or other annuals are the dominant species. As with the situation described above, no scheme of grazing management will improve these ranges. The only way improvement can occur is through seeding these ranges with adapted species. This requires removal of the competing annuals, preparation of a seedbed, and the seeding of the proper species or mix of species. The management of seeded stands becomes quite important and this will be discussed later.

Studies have been made on the best ways to utilize the highly palatable but short-lived green cheatgrass forage in southern Idaho (Murray 1971). Grazing capacities of cheatgrass and native bunchgrass pastures were similar in wet years but were almost 60% greater on bunchgrass ranges in dry years when cheatgrass production was quite low. Sheep gains per acre were similar on the two range types.

SEEDED RANGES

Sagebrush-grass ranges that have been seeded offer both opportunities and challenges in terms of grazing management systems. Most sagebrush ranges have been seeded to introduced species of grasses because there are so few native grasses, legumes, or other forbs available that are adapted or that will persist. The current trend to encourage use of native species, at least on reclaimed mined areas, should not influence a manager to seed native species on sagebrush-grass ranges except in very special situations. The available introduced grass species are far superior to native species in terms of earlier growth in the spring and, for most species, resistance to grazing pressure (Laycock 1981, 1982).

Because of these characteristics, stands of seeded introduced grasses must be grazed under different management systems than the native sagebrush-grass vegetation they replaced. A great many managers, especially in public land management agencies, have failed to recognize this. They have tried to manage seeded ranges just like the native ranges--resulting in a drastic underuse of the seeded stands and, in some cases, continued overuse of the native range. Seeded stands can take grazing pressure off the native range, especially in the spring, allowing the native ranges to maintain or increase in productivity.

The crested wheatgrasses (Agropyron desertorum and A. cristatum complex) have been the major grasses planted in the sagebrush zone. Other wheatgrass species and Russian wildrye (Elymus junceus) also are widely used.

The most common mistakes made in the utilization of crested wheatgrass are grazing either too lightly or too late to make the maximum use of its early forage. Crested wheatgrass starts growth several weeks earlier than the native grasses in most areas and grows rapidly during this early growth period. If crested wheatgrass is not grazed before flower stalk formation, it becomes coarse and stemmy and livestock will not properly utilize the forage. Wolf plants can develop which are a deterrent to grazing in subsequent years. Grazing systems with complete growing seasons or entire years of rest (such as rest-rotation) are not suited for vigorous stands of crested wheatgrass; however, they might be used to thicken weak or sparse stands.

A large amount of literature exists on the management of crested wheatgrass. Much of it indicates that crested wheatgrass can be used rather heavily over a relatively long period of time without serious damage to the stand. In Utah, Frischknecht and Harris (1968) found that 65% annual spring use of crested wheatgrass caused no major damage to the stands. In New Mexico, Springfield (1963) found that 65-70% annually use of crested wheatgrass maintained the stands and produced satisfactory cattle gains. In Saskatchewan, a crested wheatgrass pasture utilized an average of 70% in early summer was more productive at the end of a 6-year period than a pasture grazed an average of 50% (Lodge et al. 1972). Fifty percent use of crested wheatgrass in Idaho likewise produced favorable results (Sharp 1970). This does not mean that crested wheatgrass cannot be damaged by prolonged abusive grazing. Studies in Nevada indicated that repeated very early grazing caused downward trend in some, but not all, crested wheatgrass stands (Robertson et al. 1970). The reinvasion of sagebrush is a chronic situation, even in seeded stands, and periodic control of the sagebrush is required to maintain the production of the seeded stands (Frischknecht 1979). Fertilizer (usually N) can sometimes be used to increase yields on old seeded stands that have stagnated.

REINVASION OF SAGEBRUSH

Reinvasion of sagebrush is also inevitable on native areas where the sagebrush has been reduced or removed by treatment. It is assumed by most managers that proper grazing will slow the rate of sagebrush invasion, but this is not necessarily true. This was demonstrated on the Arizona strip where Hughes (1980) found, in areas where sagebrush had been reduced by riling, that sagebrush increased significantly over a 25-year period both inside exclosures and outside in areas under rest-rotation. His conclusions were:

"Grazing systems (rest-rotation, deferred) in arid sagebrush zones by all appearances seem to be a waste of money unless land treatment (chaining, burning, etc.) is a recurring event with the grazing system to keep the sagebrush canopy very open and patchy. A grazing system would keep grasses vigorous; however, it would not slow sagebrush reinvasion."

Extremely heavy or abusive grazing can hasten the reinvasion and growth of sagebrush on both native and seeded ranges. However, at grazing intensities

short of these extremes, the system of grazing, including complete rest from grazing, does not seem to have any influence on rate of reinvasion of sagebrush.

ROLE OF SPECIALIZED GRAZING SYSTEMS ON SAGEBRUSH-GRASS RANGES

Most specialized grazing systems increase stocking density (animals per unit area) but shorten the period of grazing. In all systems, this is intended to get better livestock distribution, and, in some systems, it is intended to force more uniform grazing of all forage species regardless of palatability. Different systems have different objectives, but all such systems have an increased number of pastures so that a period of rest can be given each pasture to allow plants to recover after grazing.

Rest-Rotation Grazing

Rest-rotation grazing is the specialized system that has been most often applied to sagebrush-grass ranges on both BLM and Forest Service lands. What have been the results of studies? The Harvey Valley Allotment in California was the site of the first rest-rotation study on ranges that included big, low, and silver sagebrush types, as well as open grassland and timber types. After analyzing data from a five-pasture system grazed by cattle over 12 years, Ratliff et al. (1972) concluded that rest-rotation grazing was superior to season-long grazing, that range health at Harvey Valley relative to nearby allotments is better, and that range condition trend is upward.

Ratliff and Reppert (1974) reported somewhat different conclusions based on data collected in the Harvey Valley study from 1965 to 1969: (1) "continuous grazing appears to be more effective in controlling competing vegetation than it is damaging to Idaho fescue," (2) "the full use treatments did not reduce nor did full-season rest improve Idaho fescue vigor on the Harvey Valley plots," and (3) "it appears that range managers cannot key seed production into a set program of rest-rotation grazing."

On native mountain big sagebrush-grass range on the Ashley National Forest in eastern Utah, a comparison of summer-long grazing by cattle every year vs. three-unit rest-rotation systems revealed no differences in cover, yield, or species composition of vegetation after 7 years (Laycock and Conrad 1981). Average daily gains of cattle over the entire period were similar for all systems. All areas were in fair to good condition and were grazed at a moderate intensity. The lack of difference between systems was attributed to the same level of all other management factors (water, salt, riding, etc.) being applied to all systems.

Observations on the BLM Pleasantview Cattle allotment in southeastern Idaho indicated variable results from a three-unit rest-rotation system that had been in operation for approximately 10 years (Blaisdell et al. 1982). Fair-condition mountain sagebrush-grass areas on moderate to steep slopes appeared to be receiving light or moderate use and

the trend was upward. On the other hand, many of the more gentle slopes still had a thick stand of sagebrush and little understory of desirable grasses and forbs with no evidence of upward trend. Likewise, canyon bottoms, areas around water developments, and aspen or chokecherry groves used for shading-up were often in depleted or poor condition and showed no evidence of improvement.

Eckert and Spencer (in press) evaluated rest-rotation grazing management on two allotments in northern Nevada from 1974 to 1982. The response to management was evaluated by shrub canopy cover, basal area of herbaceous species, frequency of occurrence of all species, and amount of bare ground. Forage use was heavy in all years and no definite trend in range condition was evident after 7 to 9 years of rest-rotation management.

Ratliff and Reppert (1974) concluded from the Harvey Valley study that rest-rotation grazing was primarily a procedure for restoring rather than maintaining range health. Two major advantages of the system were considered to be that the rest areas could provide emergency use in severe drought years, and that it provided opportunities for cultural range improvements.

Young et al. (1979) stated that:

"Preliminary results indicate that rest-rotation grazing is a useful management system for sagebrush/grasslands in fair to high condition. For degraded sagebrush/grasslands with an overabundance of brush and little or no seed source for perennial grasses, rest-rotation grazing as a technique for range improvement is little more than wishful thinking."

Blaisdell et al. (1982) concluded that:

"Although rest-rotation grazing has been widely accepted as a panacea for range management problems, data are not available to demonstrate its real worth or to sort out the contribution of such important factors as plant control, revegetation, water development, fencing, and removal of trespass livestock—all of which have accompanied the application of rest-rotation grazing on Federal ranges. Certainly, there is no conclusive proof that rest-rotation is more effective than other systems on most sagebrush-grass ranges."

Mueggler (1972) pointed out that a problem may have been created by extending rest-rotation grazing to all types of range. Logic indicates that this grazing system has a better chance of succeeding on grasslands, where most of the vegetation is fairly palatable, than on ranges where unpalatable species such as sagebrush and wyethia are prominent components of the stand and can take advantage of reduced competition. In any event, it seemed necessary to balance desirable effects of heavy use that often are associated with rest-rotation grazing against undesirable effects on wildlife habitat, watershed protection, esthetics, and livestock weights.

Hughes (1983) asked the question:

"Do grazing systems maintain or rehabilitate vegetation types as well as areas protected from grazing? In the sagebrush type, cool-season grasses and browse, by a small margin, did better under protection from grazing. Warm-season grasses and shrubs occurred more frequently under grazing. This pattern generally held true under rest-rotation grazing as well as continuous grazing (with moderate utilization)...Protection from grazing, like grazing systems, must be applied only where needed and where improvement can occur and it will then bring ecological and economic return."

Eckert and Spencer (in press) studied rest-rotation grazing in northern Nevada, and speculated that an upward trend in ecological range condition, as indicated by an increase in the composition of desirable species, will be strongly influenced by ecological range condition at the time management is initiated. An upward trend on rangelands in early-seral condition will be extremely slow or will not occur at all because grazing pressure will continue on the few remaining desirable plants, little or no seed will be produced by desirable species, and competition from sagebrush will prevent establishment of seedlings of desirable species. On sites in late-seral condition, upward trend also will be slow because competition will prevent recruitment of new individuals of desirable species except on rare occasions. The best opportunity to obtain an upward trend may be on sites of mid-seral condition. Under proper management, vigor, growth, and seed production of desirable species is enhanced. Then as the less desirable short-lived perennials become senescent and die, the major seed source will be that of desirable species.

Eckert and Spencer (in press) concluded that, if rest-rotation grazing will maintain vegetation in late-seral condition and improve vegetation in mid-seral condition, it is a valuable management tool. If rest-rotation grazing can only maintain early-seral vegetation in an unimproved condition, then such areas are candidates for range improvement practices.

Other Specialized Grazing Systems

Most of the current highly publicized grazing systems now being promoted are variations of Short Duration Grazing (SDG). This includes the Savory Grazing Method as well as many others. Most SDG systems involve a relatively large number of pastures (usually 8 or more), high stocking density, relatively short periods of grazing (often only a few days), and long rest periods to allow plants to recover vigor after being grazed. There probably are some SDG systems being applied on sagebrush-grass rangelands, but I don't know of any published results. Such systems probably will not result in improvement of sagebrush ranges in poor condition, for the reasons previously discussed. These systems might be quite useful, however, on seeded rangelands where more intensive management is required.

Situations Requiring Specialized Systems

A grazing system involving some sort of rotational use might be needed for a sagebrush-grass range when certain preferred species or sites become "sacrifice" areas under continuous use (personal communication, R. E. Eckert, Reno, NV). For example, on areas with riparian habitat, continuous or summer-long use by cattle might result in overuse of the riparian zone early in the season. On federal land, this would call for early removal of the cattle before any substantial use had been made of the uplands. In effect, this situation forces some sort of a grazing system--either fencing to manage the riparian area separately or subdivision of the entire rangeland into units that are more intensively grazed by larger numbers of cattle for shorter periods in a rotation system. Hyder and Bement (1972) stated: "Drainage systems, for example, are unacceptable for sacrifice...When they cannot be given an opportunity to grow freely every year, as under continuous grazing, they should be given that opportunity every other year, every third year, or at some interval of time that will permit renewal of vigor and productivity. This simple fundamental truth is sufficient to justify rest periods, which in turn require rotational grazing."

Data to substantiate the benefits of a grazing system to protect riparian areas in sagebrush-grass vegetation are difficult to find. On a cattle allotment in southeastern Idaho where a 3-unit rest-rotation system had been in effect for 10 years, Blaisdell and others (1982) found that areas where cattle naturally congregate were still in depleted condition and showed no evidence of improvement. In this situation, perhaps the only answer may be fencing the riparian areas.

Another advantage of any specialized system with a number of pastures is that it does allow periodic or systematic sagebrush reduction or control in one part of the range without disrupting the management system and causing severe problems on the rest of the range. Several authors have pointed out this advantage of rest-rotation systems, which could also apply to multiple pasture SDG systems.

CONCLUSIONS

Native Sagebrush-Grass Ranges

Any grazing system that results in heavy use of the herbaceous understory species during the growing season, even for a short period, has a chance to cause deterioration of native sagebrush-grass ranges. Because the sagebrush is not utilized, it can respond to reduced competition due to the deterioration of the herbaceous species and become more competitive with them (Mueggler 1972). In areas of low growing-season precipitation, even moderate use of perennial herbaceous species may place them at a severe competitive disadvantage over the nonpalatable and well-adapted shrubs. A factor that has been ignored in most studies is the potential differential response by different subspecies of sagebrush or different habitat types to grazing.

From these observations, it would seem logical to conclude that any highly specialized grazing system can do no more than maintain condition of most native sagebrush ranges, and such systems probably have the potential to cause damage. This would apply to both rest-rotation and more specialized systems such as SDG. If Eckert and Spencer (in press) are correct, rest-rotation may be useful for improving sagebrush grass ranges in mid-seral condition, but the rate of improvement will be slow. Grazing systems may also be useful for allowing riparian areas to be maintained in better condition or when periodic sagebrush control is needed without disrupting the grazing schedule.

Seeded Range

Seeded sagebrush-grass ranges must be managed differently than native sagebrush ranges. Seeded areas managed like native range to obtain light early spring use or rotation of use involving long deferments lose much of their potential advantage to a livestock operator. Likewise, seeded range, especially those seeded to crested wheatgrass or Russian wildrye, do not lend themselves to specialized grazing systems that require complete years of rest. This is because these grasses exhibit early growth, low palatability after flower stalks are formed, rather high resistance to damage caused by grazing, and a tendency to form wolf plants when not grazed. Because of these characteristics, a rest-rotation system involving only crested wheatgrass or crested wheatgrass in one pasture with several native range pastures does not make much sense for most situations (Laycock 1983). However, some specific plan of grazing must be developed to take advantage of the characteristics of seeded species.

In most cases, crested wheatgrass and other seeded species can withstand rather heavy spring use every year with little damage. This may be the best management scheme for many specific situations because of its simplicity and low cost. The early spring use allows an operator to go on green feed earlier and also to rest his native range somewhat longer in the spring. Some form of short duration grazing, with rapid rotation through a series of pastures, might be the best system in areas where there is sufficient spring soil moisture for a prolonged period (6 weeks or more) of green growth of crested wheatgrass. Such a system might keep the crested wheatgrass in a vegetative stage longer, result in good livestock gains per animal, increase livestock gains per acre, and maintain the vigor and productivity of the crested wheatgrass stand.

Sagebrush will slowly return to most seeded stands, so some form of sagebrush control will be needed at the time the shrubs begin to reduce the productivity of the seeded stand. Fertilizer (N) application might also be needed periodically to increase yield of older seeded stands.

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TIME AND DATA NEEDS IN THE ECONOMIC ANALYSIS OF RANGE MANAGEMENT DECISIONS

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ABSTRACT

Decisions on rangeland improvement practices are complex because of: (1) the variety of uses of rangeland; (2) interrelationships among climate, soils, animals, management, and rangeland productivity; (3) alternative control methods and their associated costs and effectiveness; (4) the extended life of the physical response from range improvements; and (5) difficulties in valuing the increased forage from range improvement practices. These complexities of range improvement decisions were addressed in the suggested five main procedural steps of range management decisions:

- 1) Problem identification;
- 2) Identification of management techniques and their costs;
- 3) Quantification of physical response from management techniques;
- 4) Valuation of the output; and
- 5) Selection of management technique.

Regardless of the rangeland problem being addressed, these general procedural steps will have to be followed in evaluating the economic feasibility of the proposed management practice being considered. The economic analysis in following the procedural steps points out (1) the importance of considering several alternative management or improvement techniques, (2) the necessity of physical response data over time, (3) that valuation is based on the net change in output for the "with" vs "without" project situation, (4) that valuation requires an estimate on the value of the additional amount of forage, and (5) the need for discounting in determining the economic feasibility of an improvement practice or in selecting among improvement practices. The economic analysis of range improvement practices also indicates that the two areas where research is needed most are (1) determining the physical relationship between uses as well as the physical response for alternative improvement practices, and (2) of valuing recreation and wildlife uses of rangeland.

INTRODUCTION

The sagebrush-grass ecosystem is dominated by the woody species of *Artemisia*, with an understory of perennial grasses and forbs (Blaisdell, et al., 1982). It occupies a substantial portion of the range in the western United States. It is found over much of Utah, Nevada, Wyoming, Colorado, southern Idaho, eastern Oregon, and western Montana,

and in some areas of Washington, California, Arizona, and New Mexico (Blaisdell et al. 1982). Acreages of sagebrush-grass rangeland vary from 95 million acres, estimated by the Forest Service in 1972, to 270 million acres, estimated by Dr. Beetle, University of Wyoming, in 1960 (Blaisdell et al. 1982).

While sagebrush-grass range is often perceived as being fairly uniform, it is a complex and diverse resource. This complexity and diversity can at least be partially attributed to the variety of plants and wildlife that inhabit rangeland, and of uses made of rangeland. It is not only an important resource in the production of livestock and wildlife, but also has value as a watershed and provides a wide variety of recreational activities. Because of the many different uses made of rangeland, perceptions of rangeland and its value vary greatly. Regardless of one's perception, its sheer size, accessibility, and productive potential make the sagebrush-grass range ecosystem an important natural resource to be maintained or improved in satisfying a variety of needs.

While the demands placed on the sagebrush-grass rangeland are many, the dominant demand or use has been, and continues to be, livestock grazing. Thus, a majority of the management decisions are related to livestock grazing. What are some of the management decisions in the use of this ecosystem?

RANGE MANAGEMENT DECISIONS

The primary concern in managing sagebrush-grass range is that of maintaining sufficient perennial grasses and forbs. The overall management objective might be expressed as "maintaining vegetation to sustain the optimum level of livestock and wildlife consistent with other uses of the rangeland."

The prevalent problem of sagebrush-grass range is an over-abundance of sagebrush and other shrubs which reduces the production of perennial grasses and forbs. The question of whether to restore desirable vegetation through range improvement and/or livestock grazing practices is a major management decision. While the question appears simple, the appropriate answer requires the application of considerable knowledge and planning because of the inherent interrelationships among climate, soils, plants, and animals. These interrelationships must be considered in the manager's attempt to manipulate vegetation by mechanical, chemical, and/or biological means. Furthermore, there are several other decisions, such as water development, weed control, grasshopper control, stocking rate, recreational use, and others, that also have to be made in managing sagebrush-grass range. While these decisions may come at different times and under different circumstances, the decision process can be broken down into several main procedural steps.

The main aspects or procedural steps in range management decisions, which generally involve long-term adjustments and impacts, are as follows:

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- 1) Problem identification;
- 2) Identification of management techniques and their associated costs;
- 3) Quantification of physical response from management techniques;
- 4) Valuation of the output; and
- 5) Selection of management technique.

While this paper concentrates on the control of sagebrush, the procedural steps outlined above also apply to other range-management decisions, such as controlling weeds or insects.

Problem Identification

Identification of the problem is frequently viewed as being quite simple or easy. For a grasshopper infestation, this may be true, but, at the same time, it may be quite difficult to decide whether control is economically justified. For sagebrush, the problem is identifying a site where (1) the infestation of sagebrush is dense enough to cause a significant reduction in forage yield and (2) the potential increase in forage production with range improvement would be sufficient to economically justify the improvement practice. The ability to recognize such things as animal production, vegetative condition, and potential forage yield are important in evaluating the need for and success of range improvement practices.

Identification of Management Techniques

Owners and managers of sagebrush-grass rangeland are periodically faced with decisions on investments in management techniques to maintain and/or improve its productivity. Decisions concerning these investments are largely a function of (1) the range's productivity, (2) whether productivity of the range will continue to deplete and the rate of depletion, (3) the potential recovery of the range and the rate of recovery after treatment, (4) the rancher's opportunity cost of investment (discount rate) and (5) the improvement technique (Cotner 1963).

While decisions to control various undesirable plants and insects of sagebrush-grass range have to be made from time to time, big sagebrush (*Artemesia tridentata*) is frequently the target species. Spraying, burning, and mechanical methods have all been used to control sagebrush. As with most decisions, the best control technique depends on various factors, such as age and density of the sagebrush, other undesirable shrubs, grasses present in the understory, precipitation, soil type and depth, topography of the area and potential for erosion, equipment requirements, planned use for the area, productivity of the range after control, and the cost of the control method (Blaisdell et al. 1982). This same argument can be made regarding the control of other rangeland pests. Thus, whatever the pest being controlled, a number of factors must be considered in evaluating alternative methods for controlling it.

Quantification of Physical Response from Management Techniques

Perhaps the most difficult aspect of evaluating the control of undesirable plants and insects on rangeland is that of determining the physical response of rangeland to a management practice. Estimating rangelands' physical response to management practices on a particular site is difficult because of the diversity of complex interrelationships between climate, soil, plants and animals, and rangeland productivity. Determining the physical response of rangeland to management practices is also difficult because of the time involved in obtaining the yield response.

Time has two important aspects with regards to pest management decisions on rangeland. One aspect is the timing of the particular control practice. For example, in controlling grasshoppers, timing is important in that early control allows some unhatched grasshoppers at the time of control to hatch and reinfest later. On the other hand, late control allows some egg-laying to occur before control with the eggs being a source of infestation for the following year. To spray sagebrush, Freeburn (1979) indicates that the best time to spray in Wyoming is from mid-May to mid-June. To burn sagebrush, Blaisdell et al. (1982) indicate that the best time is in early fall. Early spring burning is also a good time as damage to other species is minimal; however, timing is critical as proper conditions only last for a few days (Blaisdell et al. 1982). Thus, timing of the management practice is extremely important in determining its effectiveness.

The other aspect of time relates to the physical response of rangeland to the management practice over time. This physical (yield) response to a management practice can be broken into three components or periods; (1) the rate and level of the increase in physical response, (2) life of the maximum level of physical response, and (3) rate of decline of the physical response. This response characterizes the kind of relationship that generally exists between management practices and rangeland productivity. To quantify this relationship, studies of rangeland improvements need to cover rather long time spans. This, in turn, requires researchers and their administrators to make long-term commitments of time and funds to complete the research project. However, it should be pointed out that meaningful economic analyses of management practices cannot be made until the physical responses are identified and quantified.

Research reports on the physical response of rangeland to sagebrush control indicate a substantial increase in forage production can be expected. For the alternative mechanical sagebrush control methods of railing, rotary beater, and patrol with no seeding, Kearl and Brannan (1967) report an increase in forage production of 152, 133, and 77 percent, respectively. Based upon observation of the control site, a control life of 12 years was projected for railing and rotary beater and 15

years for patrol without seeding. Peak yields occurred 2 years after control (Karl and Brannan 1967).

A 30-year study of a prescribed burn on an area supporting a dense stand of sagebrush reported forage production of most grasses on the burned area ranged from about 100 to 250 percent of production on unburned range.

(Blaisdell et al. 1982). Forage production decreased the first year after the burn, but then increased for about 11 years and finally began to decline with production returning close to its preburn level with 30 years (Blaisdell et al. 1982).

Of the methods for controlling sagebrush, spraying with 2,4-D has been the method most widely used. In a study on the economics of spraying sagebrush, Freeburn (1979) reported, based on experimental data of Alley (1965) that forage production can be expected to increase 300 to 400 percent over the precontrol level in a period of 3 to 5 years. In a survey of 207 ranchers across Wyoming (Freeburn 1979), the reported increase in forage production after spraying averaged 137 percent. The Forest Service has collected prespray and postspray data on forage production for some spray areas. Based on the sites and years sampled, Freeburn (1979) concluded that productivity appeared to be sustained on the sites sampled through 12 years. Other locations sprayed before the Forest Service started sampling showed good results for more than 20 years; that is, sites sprayed in 1957 and 1959 were still free of brush and highly productive in 1979 (Kearl, personal communication). In his economic analysis of sagebrush spraying, Freeburn (1979) had the usable forage production doubling in 2 years, forage production being sustained for years 3 through 10 and then forage production declining to the prespray levels in years 11 to 15.

In this example, the specified change in forage use as a result of sagebrush spraying was as follows:

Year	Forage Use
0	Spray; no change in forage use
1	No change in forage use
2	Forage use increased 50%
3	Forage use increased 100%
4-10	Forage use level sustained
11-15	Forage use declines to prespray level.

This change in forage use is depicted in figure 1. The 100 percent increase in forage use is conservative but consistent with the reported increases in forage production of 150 to 300 percent. This represents an estimate of the physical response of rangeland to sagebrush spraying over a 15-year period. This physical response is then used in the economic evaluation of sagebrush spraying.

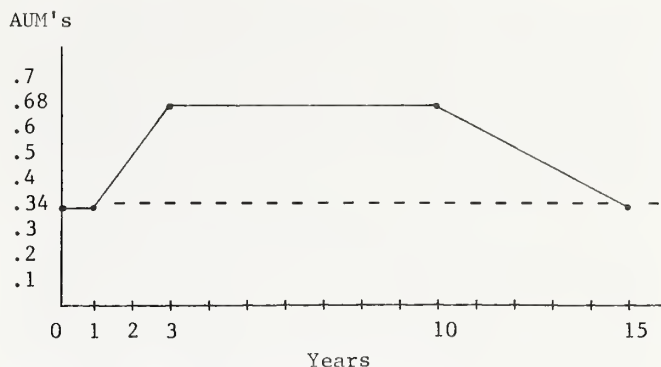


Figure 1.--Change in forage use associated with sagebrush spraying.

Valuation of Increased Output

The additional forage production resulting from sagebrush control could be considered either an intermediate or end product. It is generally an intermediate product in that the forage is generally used by the livestock enterprise on the ranch. If the sprayed rangeland were rented out, the increased forage could be considered an end product. Regardless of whether the increased forage production is considered an intermediate or end product, a basic guiding concept in determining the net change in (additional) product is the "with versus without principle." Under the "with versus without principle," the overriding question the analyst must answer is, "what is the difference between what would happen with the proposed improvement versus what would happen without the proposed improvement?" For example, the increased forage use in year 2 with sagebrush spraying is 0.17 AUMs. This is the difference between 0.51 AUMs with spraying less 0.34 AUMs without spraying. In years 3 through 10, the increased forage use due to sagebrush spraying is 0.34 AUMs (0.68 - 0.34). The point is that analysts need to be careful to assure that physical response for each year of the improvement project represents the net change "with versus without" of the project and not the combination of new and previous use.

The next step is that of valuing the estimated net changes in output. Valuation of the increased forage from range improvement decisions generally involves valuing such associate outputs as livestock, wildlife, recreation, and/or water (Godfrey 1983). There are difficulties in valuing each of these increased outputs and this is where an economist can provide assistance.

Of the outputs listed, the valuation of forage for livestock would generally be regarded as the output easiest to value. Many approaches have been used in valuing the increased forage from sagebrush control.

Perhaps the easiest approach, and the one currently suggested by the Bureau of Land Management, is to

use the value of private grazing fees (Godfrey 1984). While some economists would agree that private grazing fees are conceptually a defensible value, they may tend to overestimate the value of forage for at least two reasons. First, private grazing fees may include a number of services (for example, salting, fence repair, and herding). To be an acceptable value, these private grazing fees would have to be adjusted downward by the value of the other services provided. Secondly, private grazing fees may cover only part of the grazing season. In such situations, a rancher would only consider his variable costs in determining how much he could afford to pay for the grazing. These short-term rates would be considerably higher than a long-term arrangement where the rancher would consider both fixed and variable costs. As a result, using private grazing fees could place a value on forage ranging from \$3 to \$12 per AUM.

The significance of the value placed on the increased forage is readily understood and is illustrated in table 1. The negative \$8 in year 0 is the per-acre spray costs based on 1979 and used in a study by Kearl and Freeburn (1983). However, the per-acre spraying cost is currently \$10 to \$12 per acre. The net present value (NPV) per acre is the sum of the yearly change in net returns, including the cost of spraying in year 0, discounted at 4 percent. It can be calculated using the following formula:

$$NPV = \sum_{n=1}^T \frac{NR_n}{(1+r)^n} \quad (1)$$

Where NPV = Net present value

NR_n = Change in net returns in year n
(for example, additional returns less additional costs)

r = discount rate

n = year

The cumulated NPV is simply the sum of the yearly NPV's. With a 15-year life, sagebrush spraying

just pays for itself if the increased forage use is valued at \$3/AUM. If forage is valued at \$9/AUM, sagebrush spraying costs would be recovered in 5 years and the increased NPV over 15 years would be about \$16/acre.

An alternative approach to evaluating an investment in range improvement, such as sagebrush spraying, is to determine the internal rate of return (IRR) from that investment. The IRR is a determination of r (discount rate) in formula 1 such that the NPV equals zero over the life of the project. This means the NPV of costs is equal to the NPV of returns. The decision involves determining whether the IRR is large enough to satisfy the investor. For the sagebrush example in table 1, the IRR is 4.2 and 24.8 percent with increased forage valued at \$3 and \$9/AUM, respectively. Thus, determining the value to place on the increased forage production is not easy and it has a major influence on the economic evaluation.

Two other factors that influence the economic evaluation are the discount rate and the life of the range improvement practice. The question of the appropriate discount rate has probably received more discussion and debate among economists than any other topic. The controversy is too extensive to discuss in this paper. However, the significance of the discount rate in the evaluation of proposed projects is well recognized. For example, in the previous evaluation of sagebrush spraying, increasing the discount rate from 4 to 8 percent results in cumulated NPV's over the 15-year period of \$-1.73 and \$10.83/acre with the increased forage valued at \$3 and \$9/AUM, respectively.

The expected life of the range improvement practice also has a major effect on the economic evaluation of that improvement practice. In the sagebrush spraying example, the range improvement practice was assumed to influence forage production over a 15-year period. It is not apparent from the

Table 1.--Valuation of sagebrush spraying using private grazing fees

Year	Increased yield AUM's	\$3/AUM		\$9/AUM	
		Net present value (dols.) ^{a/} per acre	cumulated	Net present value (dols.) ^{b/} per acre	cumulated
0	0	-8.00	-8.00	-8.00	-8.00
1	0	0	-8.00	0	-8.00
2	.17	.47	-7.53	1.41	-6.59
3	.34	.91	-6.62	2.72	-3.87
4	.34	.87	-5.75	2.62	-1.25
5	.34	.84	-4.91	2.52	1.27
6	.34	.81	-4.10	2.42	3.69
7	.34	.78	-3.32	2.33	6.02
8	.34	.75	-2.57	2.24	8.26
9	.34	.72	-1.85	2.15	10.41
10	.34	.69	-1.16	2.07	12.48
11	.27	.53	-.63	1.59	14.07
12	.20	.38	-.25	1.15	15.22
13	.14	.25	0	.74	15.96
14	.07	.12	.12	.35	16.31
15	0	0	.12	0	16.31

^{a/}The increased yields are from figure 1.

^{b/}Net present values were calculated using a 4-percent discount rate.

literature on sagebrush spraying that its effect on forage production is limited to a 15-year period. The expected life of range improvement through sagebrush spraying may, in fact, be considerably longer than 15 years. Kearl and Freeburn (1983) used an expected life of 22 years in their economic evaluation of sagebrush spraying. In a study of a prescribed burn, it was reported that 30 years after burning forage production from grasses was near the pre-burn level (Blaisdell et al. 1982). The effect of extending the life of range improvement by sagebrush spraying is illustrated in table 2. The accumulated NPV's over 30 compared to 15 years increases from \$0.12 to \$3.87/acre and from \$16.31 to \$27.65/acre with the increased forage use valued at \$3 and \$9/AUM, respectively. Looking at the IRR of return, it increased from 4.2 to 8.3 percent and from 24.8 to 26.3 percent over 30 years with the increased forage valued at \$3 and \$9/AUM, respectively. Thus, the value per AUM, the discount rate, and the life of the improvement practice are all important considerations in evaluating range-improvement practices.

Another consideration in valuing the increased forage use is related to the planned use of that forage. The above approach may be best if the planned use of the improved rangeland is to lease it for grazing. However, if the rancher plans to use the forage in his livestock operation, then

complete budgeting of his operation may be the better approach in valuing the increased forage.

An example of this approach is Freeburn's (1979) analysis of the economics of sagebrush spraying in Wyoming. Utilizing ranch budgeting and discounting returns for a cow-calf-yearling operation with a breeding herd of 500 cows, Freeburn evaluated the net returns from sagebrush spraying over a 15-year period. Sagebrush spraying was evaluated by comparing the initial ranch model to a model of the ranch with the same resources, except for the range improvement project of spraying sagebrush. In one situation, Freeburn (1979) evaluated the increased forage from sagebrush spraying by expanding the breeding herd. With the expanded herd size, the number of cattle marketed, value of sales, and costs of production all increase. General assumptions used by Freeburn (1979) in evaluating this situation were: (1) 1,500 acres of sagebrush are sprayed, yielding 510 additional AUM's during the maximum production period of years 2 through 10; (2) the increased production is used to carry 48 additional cows and the associated cattle; (3) calf crop remains at 84 percent, the same as in the basic mode; and (4) marketing weights and prices of all cattle remain the same as in the basic model. Based on these assumptions, the various actions of the ranch operator for the sprayed ranch model over the 15-year period are summarized below (Freeburn 1979).

Table 2.--Valuation of increased forage from sagebrush spraying using private grazing fees

Year	Increased yield AUM's	\$3/AUM		\$9/AUM	
		Net present value (dols.) ^{a/} Per acre	Cumulated	Net present value (dols.) ^{a/} Per acre	Cumulated
0	0	-8.00	-8.00	-8.00	-8.00
1	0	0	-8.00	0	-8.00
2	.17	.47	-7.53	1.41	-6.59
3	.34	.91	-6.62	2.72	-3.87
4	.34	.87	-5.75	2.62	-1.25
5	.34	.84	-4.91	2.52	1.27
6	.34	.81	-4.10	2.42	3.69
7	.34	.78	-3.32	2.33	6.02
8	.34	.75	-2.57	2.24	8.26
9	.34	.72	-1.85	2.15	10.41
10	.34	.69	-1.16	2.07	12.48
11	.32	.63	-0.53	1.87	14.35
12	.31	.57	0.04	1.74	16.09
13	.29	.52	0.56	1.57	17.66
14	.27	.47	1.03	1.40	19.06
15	.26	.42	1.45	1.30	20.36
16	.24	.38	1.83	1.15	21.51
17	.22	.34	2.17	1.02	22.53
18	.20	.30	2.47	0.89	23.42
19	.19	.27	2.74	0.81	24.23
20	.17	.23	2.97	0.70	24.93
21	.15	.20	3.17	0.59	25.52
22	.14	.17	3.34	0.53	26.05
23	.12	.14	3.48	0.44	26.49
24	.10	.12	3.60	0.35	26.84
25	.08	.10	3.70	0.27	27.11
26	.07	.07	3.77	0.23	27.34
27	.05	.05	3.82	0.16	27.50
28	.03	.03	3.85	0.09	27.59
29	.02	.02	3.87	0.06	27.65
30	0	0	3.87	0	27.65

^{a/}Net present values were calculated using a 4-percent discount rate.

<u>Year</u>	<u>Action</u>
0	1,500 acres of sagebrush range are sprayed.
1	Grazing remains at prespray level, additional hay is purchased and cattle sales are reduced because of increased requirements for replacements to achieve an increased herd size.
2	Grazing use doubles on the 1,500 acres sprayed. There is no increase in cattle sales and additional hay is purchased for winter feed because of the increased herd size.
3-10	Grazing use on 1,500 acres remains at double the prespray level, cattle sales expand and additional hay is purchased for winter feed because of the increased herd size.
11-15	Grazing use, herd size, cattle sales, and purchased hay costs all gradually decline to the prespray level.

Taking the yearly differences in net returns between the initial ranch model and the expanded ranch model after spraying, and discounting at 6 percent, Freeburn (1979) estimated the cumulated increase in NPV because of spraying 1,500 acres of sagebrush range was \$4,811. For the 1,500 acres of rangeland, this would be an increased NPV of \$3.21 per acre or an internal rate of return of about 1.28 percent.

As an alternative approach, Freeburn (1979) evaluated sagebrush spraying by comparing a ranch model with a relatively heavy stocking rate to a ranch model with the same resources, except for a sagebrush spraying project on 1,500 acres of the rangeland. In this case livestock numbers remained at prespray levels, which can be inferred to mean that grazing intensity is lower for the entire ranch because of the increased productivity on the 1,500 acres of rangeland sprayed to control sagebrush. The general assumptions used by Freeburn (1979) to evaluate whether the use of sprayed sagebrush range to reduce grazing intensity would be economically feasible were: (1) 1,500 acres of range are sprayed, yielding 510 additional AUM's; (2) spraying allows overall range utilization to decrease from 60 to 54 percent; (3) calf crop increases from 80 to 84 percent for the sprayed ranch model; (4) market weights increase by 15 lbs., 30 lbs., 40 lbs., and 25 lbs. for calves, yearlings, cull cows, and cull two-year old heifers, respectively, with the sprayed ranch model; and (5) prices of all cattle remain the same as in the heavily grazed ranch model. Using these assumptions, actions of the ranch operator used by Freeburn (1979) for the sprayed ranch model over a 15-year period are summarized as follows:

<u>Year</u>	<u>Action</u>
0	1,500 acres of sagebrush range is sprayed.
1	Grazing remains at prespray level with no change in returns or costs.

2	Grazing use doubles on the 1,500 acres sprayed with some increase in calf crop and cattle weights.
3	Grazing use on 1,500 acres remains at double the prespray level, with additional increases in calf crop and cattle weights.
4-10	Grazing use on 1,500 acres remains at double the prespray level, calf crop and cattle weights reach a maximum.
11-15	Grazing use on the 1,500 acres, calf crop and cattle weights all decline in a straight-line manner to the original pre-spray level.

Based upon these changes due to reduced grazing intensity on the sprayed ranch model compared with the heavily grazed ranch model, Freeburn (1979) estimated the economic feasibility of sagebrush spraying. Again, by taking the yearly differences in net returns between the heavily grazed ranch model and the sprayed ranch model with reduced grazing intensity and discounting at 6 percent, he estimated the cumulated increase in NPV over 15 years associated with the spraying of 1,500 acres of sagebrush range was \$29,904. For the 1,500 acres of rangeland sprayed, this would be an increased NPV of \$19.93 per acre. The IRR with the 1,500 acres of sagebrush sprayed and reduced grazing intensity is just over 50 percent.

The ranch budgeting approach used by Freeburn provides ranch operators with an estimate of the value of the additional forage resulting from sagebrush spraying. A primary difficulty in using this approach is that of obtaining the necessary data to conduct ranch budgeting under alternative management strategies. Another shortcoming of this approach is that the forage value derived from the differences in net income for these ranch models is for the particular case specified. As a result, the value may not reflect the value for any single ranching operation as the conditions on each ranch differ. Recognizing these limitations, ranch budgeting can be used to provide reliable estimates of the value of increased forage production from range improvements designed to benefit livestock production.

These approaches and problems were discussed to illustrate that there is not a single best method for evaluating the value of increased forage from range improvements. It also illustrates that three major factors influencing the value of increased forage associated with range improvement are; (1) the level and expected life of the increased physical response from the range improvement practice, (2) the discount rate used, and (3) the approach used to value the increased forage production. Another important factor not illustrated in these examples is the shape of the increased physical response from range improvement practices.

Each approach for valuing forage for livestock use has some problems, but valuing the increased recreational and wildlife uses associated with

increased forage from range improvement practices presents much more difficult problems. While the value of recreational activities have been estimated by various techniques in many studies, there is much debate over the usefulness of the estimates. Much of the debate centers around the issue that estimated values for recreational activities are generally average rather than marginal values. As a result, these recreational values are generally not comparable with the forage value for livestock use.

One of the most troublesome areas in valuing increased forage production on rangeland involves identifying the physical relationship between wildlife and livestock uses (Godfrey 1984). Even if the physical relationships between the uses were known, there is still the major problem of valuing the wildlife (Godfrey 1984). Perhaps the best that can be done at this time is to indicate the direction of wildlife numbers as a result of range improvement practices and the recreational value associated with these animals.

An area that has generally been overlooked is the value of range improvements for watershed considerations. Such a valuation would have to consider both water and erosion coming from rangeland. At the present time, a major consideration of range improvement practices is the potential for soil erosion associated with the range improvement practice. Research is needed in this area to establish the physical relationship between range improvement practices and water and soil erosion from rangelands.

Selection of Management Technique

Because of the extended time period over which returns from an investment in range improvements are realized, discounting is used to obtain the net present value (NPV) of the changed future net returns. Thus, discounting allows for the fact that future income has less value than present income because of foregone interest earnings and the uncertainty involved. In sagebrush spraying, there is the initial investment of the cost of spraying and a change in net returns over a number of years. The investment in the improvement practice is all made during the initial year of the project (year 0). The economic feasibility of the investment is determined by the sum of the discounted flow of NR. If the sum of the discounted NR (NPV) equals or exceeds zero,

$$NPV = \sum_{n=0}^T \frac{NR_n}{(1+r)^n} = 0$$

then the investment is recovered along with a rate of return equal to or greater than r . Furthermore, in decisions between alternative improvement techniques with similar costs, the method with the greatest NPV would be selected.

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J. Ross Wight^{2/}

ABSTRACT

Modeling provides new and innovative technology for researching and managing the vast and diverse rangeland ecosystem. Models aid in the synthesis, organization, analysis, and transfer of information, identification of research needs, and, through the process of simulation, the evaluation of management scenarios in terms of their impact on livestock production and site stability. This paper discusses briefly some of the current rangeland models including model descriptions, objectives, and potential applications. Foremost among current range models is SPUR (Simulation of Production and Utilization of Rangelands). SPUR is a comprehensive simulation model which includes a climate, hydrology, plant, animal, and economic component and a subroutine which simulates impacts of grasshoppers and their control.

INTRODUCTION

Rangelands, particularly as they are associated with arid and semiarid climates, are unique. Their climates, for the most part, support only communities of native plants which have become adapted to specific site conditions over thousands of years. Natural disturbances and mismanagement can destroy the existing climax vegetation and its soil environment such that only lower seral communities of weedy species are able to survive. This usually results in decreased productivity and increased soil erosion.

Rangeland resources are difficult to manage. Large acreages of low per acre productivity place economic limits on the intensity of management. Management responses on rangelands are difficult to measure due to the extreme spatial and temporal variation of the vegetation. Responses to treatment and management are very slow, often requiring a decade or more to become measurably evident. Variations in annual climate, especially precipitation, are extreme with year-to-year changes of 100 percent or more a common occurrence. These climatic variations confound treatment and management effects, making it difficult to interpret experimental results. Effective management of the rangelands resource requires our best management skills and the development of innovative and new management tools.

Modeling offers a new tool for both research and management. As research tools, models: (a) help sharpen the definition of hypotheses; (b) enhance communication; (c) help define and categorize the state of knowledge; (d) provide an analytical

mechanism for studying the system of interest; (e) can be used to conduct simulated experiments; (f) can be used to plan efficient real world experiments; (g) provide a key to determining the progress of research; (h) provide a method for breaking down information; and (i) can be used for prediction (USDA-ARS 1978).

As management tools, rangeland models are most effective for predicting hydrologic, plant, animal, and/or economic responses to environmental and management inputs. Long-term simulations provide a means for making management decisions by evaluating and comparing several management plans as to their impact on livestock production and site stability. Through stochastic processes, model outputs can be framed within confidence intervals, and management decisions can be made based on various levels of probability of occurrence.

The use of simulation models in range research and management is relatively new and received considerable impetus from the IBP Grassland Biome Study headquartered in Fort Collins, Colorado during the late 1960's and early 1970's. Publication of the Grassland Simulation Model (ELM) (Innis 1978) demonstrated that the processes within a grassland ecosystem could be modeled and provided methodology and direction for future modeling efforts. ELM also demonstrated the utility of models as a research tool and as an aid to resource management.

The purpose of this paper is to briefly review some of the current rangeland modeling activities. Major emphasis will be given to the SPUR (Simulation of Production and Utilization of Rangelands) model (Wight 1983). It is probably the most comprehensive range model currently being developed, and it represents the major components of a rangeland ecosystem. Much of the following discussion has been excerpted from previous presentations by the author.

RANGELAND MODELS

SPUR

SPUR is a comprehensive rangeland ecosystem model being developed as a tool for both management and research. It represents the combined efforts of both ARS and non-ARS scientists working at several locations. Model components were developed using currently available information, including models such as ELM (Grassland Simulation Model) (Innis 1978), CREAMS (A Field Scale Model for Chemicals, Runoff, and Erosion from Agricultural Management Systems) (Knisel 1980), and EPIC (Erosion Productivity Impact Calculator) (Williams et al. 1982). In general, the components in SPUR represent the state-of-the-art in their application to rangeland ecosystems.

SPUR is composed of five basic components: (1) climate; (2) hydrology; (3) plant; (4) animal (both domestic and wildlife); and (5) economic. A subroutine is available to simulate forage destruction by natural or controlled grasshopper populations. At present, this subroutine is an option and is not initiated by any model component.

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SPUR is driven by daily inputs of rainfall, maximum and minimum air temperatures, solar radiation, and wind run. These can be obtained from weather records or generated stochastically within the climate component. The stochastic generation of the climatic variables or parameters enhances the utilization of the SPUR model for long-term simulation runs and enables the model to be applied to areas where climatic data are limited.

The hydrology component calculates upland surface runoff volumes, peakflow, snowmelt, upland sediment yield, channel streamflow and sediment. It also calculates a daily soil water balance that is used to generate soil water suction pressures that control plant growth. Surface runoff is estimated by a modified Soil Conservation Service (SCS) curve number procedure and soil loss is computed by the Modified Universal Soil Loss Equation (MUSLE). Snow accumulation and melt routines in the hydrology component use air temperature as the controlling factor.

Net photosynthesis is the basis for predicting forage production. Currently, species are lumped together in functional groups such as warm season grasses or cool season grasses. Carbon and nitrogen are cycled through several compartments including standing green, standing dead, live roots, dead roots, seeds, litter, and soil organic matter. Inorganic soil nitrogen is also simulated. Photosynthesis is controlled by temperature, soil water, nitrogen, and leaf area. The model simulates competition among species plus impacts of grazing on vegetation. Inputs required include the initial biomass content of each compartment and parameters that describe species photosynthesis, respiration, and nitrogen utilization.

The animal component considers both domestic livestock and wildlife as consumers. Detailed growth information is available for cattle on a steer equivalent basis. Forage consumption is calculated for all classes of animals. Steer growth is computed by an adaptation of the Texas A & M Beef Model. The development of preference vectors based on forage palatability and site location to control plant utilization by animals is a unique feature of the model. Wildlife and insects are considered as fixed consumers and are allowed to have first access to the available forage.

Animal production or pounds of beef gain are used by the economic component to estimate the benefits and costs of alternative grazing practices, range improvements, and animal management options.

Two versions of SPUR have been developed, a grazing unit or pasture scale version and a basin scale version. The pasture scale version can simulate the growth of up to seven plant species or species groups. These species or species groups can be grown on up to nine different range sites within a grazing unit. It can accommodate the resolution of the animal component to differentially graze a pasture based on the combined effect of the preference vectors. It provides pasture or allotment level managers a method to simulate growth and grazing of the major plant species and animal production.

The basin scale version is somewhat more complex. It provides a means of predicting quantities of runoff and sediment yield for basins of up to 2500 ha with up to 27 hydrologic units (drainages adjacent to a channel), and it retains the ability to simulate plant growth, grazing, and beef production. However, the resolution of these components is diminished relative to the pasture scale version. The basin scale version uses the watershed as a management unit and is designed to answer the questions of the land manager.

To enhance the orderly development of SPUR, two developmental phases have been defined: The objective of Phase I is a SPUR model that can simulate the responses of a shortgrass prairie ecosystem in terms of aboveground plant production, cattle weight gains, soil water, and runoff. Phase I includes sensitivity analyses, documentation and preparation of a user guide. The objective of Phase II is to extend the application of SPUR to other rangeland ecosystems, validate the plant-animal interface, and include the following features which are not currently part of the model; (1) flexible grazing systems, (2) plant- and animal-hydrology feedbacks, and (3) internal parameterization of the plant component.

In Phase I, the grazing seasons are fixed and cannot be changed during a simulation. SCS curve numbers and MUSLE factors are also fixed as initial conditions and do not change during a simulation to reflect simulated changes in vegetation and/or animal impacts.

Data from the International Biological Program Study at the Pawnee site in Colorado are being used to validate the model during Phase I. Sensitivity analyses and documentation are underway and will be completed, along with user guides, in 1985. At this point, SPUR will be available for use by other scientists.

Under Phase II, the major effort will be the quantification of the plant component parameters for major rangeland forage species or species groups; the testing of the plant-animal interface, particularly the efficacy of the preference vectors; and the development of plant- and animal-hydrology feedbacks. The latter is necessary to simulate grazing and climatic impacts on runoff and erosion. The internal parameterization of the plant component is also an important feature of Phase II and will greatly reduce the number of user inputs, making SPUR more user-friendly.

ERHYM

ERHYM (Ekalaka Rangeland Hydrology and Yield Model) (Wight and Neff 1983) is a water-balance, climate, crop model that has been modified for application to rangelands. It is site specific and operates on a daily time scale. From inputs of daily precipitation, maximum and minimum air temperatures, and solar radiation, it calculates the components of a daily water budget. A ratio of cumulative actual transpiration (T) and potential transpiration (Tp) is used as a seasonal climatic index to calculate total herbage production at peak standing crop using the relationship $T/T_p = \text{actual yield/potential}$

yield, where potential yield is the range site yield with water nonlimiting. ERHYM includes the runoff and peak flow routine from CREAMS which is based on a modified SCS curve number procedure. It also includes a soil temperature simulation routine from EPIC (Williams et al. 1982) and a solar radiation and air temperature generating routine from SPUR (Hanson and Richardson 1983).

ERHYM has several research and management applications (Wight 1984). It can be used to predict total herbage yields at peak standing crop; simulate soil water and soil temperature profiles; and provide runoff and peak flow indices. The climatic index for annual growing seasons (T/Tp) can be used to normalize yield data for comparison among years and among range sites and to assist in trend analyses by accounting for climatic effects. The application of ERHYM is greatly enhanced by its simplicity of operation, accessibility of input parameters, and minimum computer requirements. It is readily adaptable to microcomputers and can be programmed in FORTRAN or BASIC. ERHYM is currently available for use. Future modifications and refinements include the addition of cumulative heat units or moving average temperatures to control growth initiation in the spring and cumulative heat units to indicate peak standing crop.

ELMAGE

ELMAGE (Ecosystem Level Model for Annual Grassland Ecosystems) (Pendleton et al. 1983) is a direct modification of ELM for use on the California annual grasslands. It was not initially designed for management application. The stated goals of this project were to "facilitate the organization of diverse information...to test hypotheses...and to suggest research direction."

Saval Ranch Model

The Saval Ranch Model (Sonntag et al. 1982) is based on cooperative research conducted near Elko, Nevada by scientists from the University of Nevada, Agricultural Research Service, U.S. Forest Service, U.S. Bureau of Reclamation, Soil Conservation Service, and the Nevada Department of Adaptive Environmental Assessment, Inc. It is a dynamic, state-dependent representation of the biological/physical/economic ranch system. The model objectives were to identify hypotheses to be tested through field research and to provide an integrated research plan. The model has four major components; vegetation, hydrology, livestock, and wildlife.

RAPPS

RAPPS (RAnge Plant ProfileS) is an Agricultural Research Service modeling effort just getting underway. As stated by Coyne (Patrick I. Coyne, personal communication) "RAPPS...seeks to use modern biological systems technology to identify plant attributes which are of primary importance in determining and therefore predicting the growth responses of forage plants to environment and management. Thus it is perceived as a model-directed program...." The RAPPS program is headquartered at Woodward, Oklahoma and will

include participation by scientists from throughout the United States. Output from the RAPPS modeling effort will provide direct input into the design and evaluation of grazing management systems.

Other Models

There are several other modeling efforts in the Agricultural Research Service that have potential application to rangelands and rangeland research. The EPIC model, which was initially developed to help determine the relationship between erosion and productivity on cultivated lands for the Resource Conservation Act (RCA) 1985 report, is currently being tested on some rangeland sites. EPIC is composed of physically-based components for simulating erosion, plant growth, and related processes, plus economic components for assessing cost of erosion and determining optimal management strategies. The components of EPIC can be grouped into nine major categories; hydrology, weather, erosion, nutrients, plant growth, soil temperature, tillage, economics, and plant environment control.

Some other models with potential rangeland application include CREAMS, SWAM (Small Watershed Model) (DeCoursey 1982a and 1982b, and SWRRB (Simulation for Water Resources in Rural Basins) (Williams and Nicks 1983). CREAMS is a field scale model with emphasis on the quality of runoff water. It could be used on rangelands to simulate the effects of applied pesticides and fertilizer on water quality. SWAM is a detailed small watershed model with a much finer resolution of input and output data than is used in either CREAMS or SPUR. It could be used on rangeland watersheds where such detail or resolution of input data was available or was required as output. SWRRB was developed for simulating hydrologic processes in large complex rural basins. It was the basis for much of the hydrology routine in SPUR.

CONCLUSION

As computer technology continues to develop, both in terms of hardware and software, models and modeling will become increasingly important. For complex systems like rangelands where cause and effect relationships are difficult to discern because of extreme spatial heterogeneity and the gradual long-term responses to management and climate, use of modeling technology is essential to effective and efficient range research and management programs.

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ABSTRACT

Most species of rangeland grasshoppers can cause economic damage. Control measures applied early in the season provide maximum protection against damage. Subtle responses to selective early treatments can produce dramatic results over time. Four insecticide treatments with unique capabilities (3 sprays and 1 bait) are registered for chemical control of grasshoppers on range. Biological control options include use of a pathogen, *Nosema locustae*, and conservation of native parasites and predators. Cultural control tactics are to avoid opening up the plant canopy and to maintain a high level of ground cover.

INTRODUCTION

Rangeland in North America is infested by a heterogeneous complex of grasshoppers that includes over 200 species. It is not unusual to encounter 30 to 40 species within an area of about 40 acres during a single season. In general, grasshoppers can occupy a variety of ecological niches or roles. Certain species can function at least partially as scavengers (Lavigne and Pfadt 1964), but the primary role is that of a herbivore. Only about 12 to 21 percent of the forage that grasshoppers consume or clip from plants is assimilated, so grasshoppers can be considered primarily a litter-making mechanism (Mitchell and Pfadt 1974). There is some evidence that plant regrowth is stimulated by moderate grasshopper grazing (Dyer and Bokhari 1976), and some species like *Hypochlora alba* and *Hesperotettix viridis* feed exclusively on plants unpalatable to livestock and thus can be considered beneficial. There are also references to grasshoppers serving as an important food supply for wildlife. However, a review of more than 100 references by Hewitt (1977) revealed three general types of damage caused by grasshoppers; (1) removal of forage in competition with livestock; (2) permanent damage to plants caused by continued feeding beyond tolerable levels; and (3) destruction of seedheads, thus preventing natural reseeding.

Different species can be destructive for different reasons, but research in Alberta revealed that 33 of 35 species studied had the potential for causing economic damage on rangeland (Hardman and Smoliak 1982). Hewitt and Onsager (1983) estimated that grasshoppers annually destroy at least 21 to 23 percent of available range forage.

Most grasshopper species overwinter in the egg stage, but a few overwinter as nymphs. Nearly all species have one generation per year, but some of the earliest species complete their development well before some of the latest species begin to hatch. In their food preferences, common species range from, at one extreme, opportunistic, almost omnivorous feeders that readily consume a variety of plant species that are conveniently available, to, at the other extreme, highly selective feeders whose survival depends exclusively on a single species of host plant. General feeders may eat a variety of grasses, a variety of forbs, or a combination of grasses and forbs.

On Montana rangeland, the hatch of each common economic species of grasshopper can occur over a 3- to 4-week period. In an intensive study of the population dynamics of 6 important grasshopper species over a 3-year period (Onsager and Hewitt 1982), the frequency distributions of first-instar nymphs approximated a normal distribution. The "normal" type distributions of first-instar nymphs over 3-4 weeks of time gave rise to similar distributions of older nymphs over approximately the same intervals of time. However, each successive instar was represented by lower mean densities because of mortality. When the distributions of successive instars of given species were plotted over time, a typical exponential density decay curve was apparent (fig. 1).

In much of the sagebrush ecosystem, about 15 abundant species are responsible for most destruction of range forage. At any given location, however, only 2 to 4 species usually comprise at least 75 to 95 percent of the total grasshopper population. The presence of a number of grasshopper species in a given habitat gives rise to a series of population curves that represent densities for the different developmental stages for each species. Each curve is one component of a total grasshopper population, and the component curves will differ in magnitude (because of different initial densities between species), in slope (because of different mortality rates between species), and in the time interval that is occupied (because of inherent differences in seasonal phenology). In spite of the obvious complexity, the problem can be simplified to a degree that would provide for practical application. Every grasshopper infestation has at every point in time an average density, an average stage of development, and an average mortality rate. If we can estimate those averages, then we are in position to estimate the potential economic significance of a given infestation. We can then also estimate the degree of suppression required to reduce the infestation to acceptable or noneconomical levels.

The rate and degree of forage destruction is a rather complex function of density, stage of development, and species composition of a grasshopper infestation. Based on observed distributions of different kinds of grasshoppers in typical rangeland populations, a theoretical "average" grasshopper weighed 81.6 mg (dry weight) in the adult stage, and consumed 9, 22, and 53 mg

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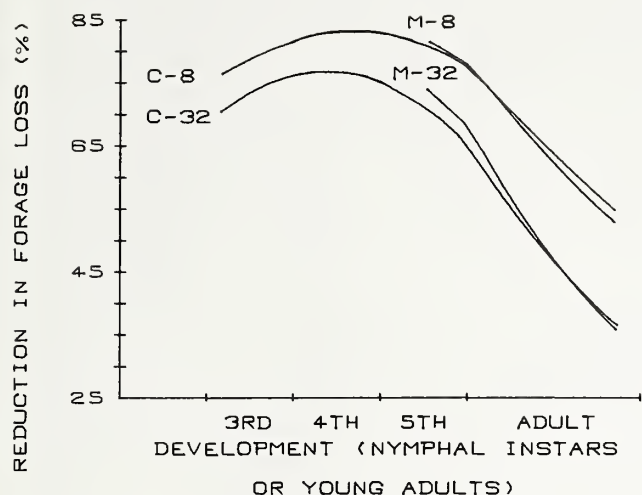


Figure 1.--Diagrammatic approximation of frequency distributions of first instar through adult stages of a grasshopper population, and a seasonal population decay curve.

of forage/day in the 4th instar, 5th instar, and adult stages, respectively (Onsager 1984). While the daily rate of forage destruction per grasshopper increases by an average factor of 2.42 with each stage of development, total daily consumption is moderated by mortality among grasshoppers over time. Under most circumstances, therefore, the rate of total daily forage destruction by a population of grasshoppers will tend to increase as the population develops, and will become maximum when most of the population reaches the adult stage (Capinera et al. 1983, Onsager 1984). Field experiments (Onsager 1978) and modeling trials (Hardman and Mukerji 1982, Onsager 1984) agree that treatments provide maximum prevention of forage destruction if applied when the preponderance of an infestation is in the 3rd or 4th nymphal instar.

Research on population dynamics has quantified natural daily mortality rates (Onsager and Hewitt 1982). The observed average daily mortality rates per species per year in natural populations ranged from 2 to 13 percent for nymphs and from 3 to 40 percent for adults. If we assume that each of 5 nymphal instars requires 7 days for development, we can calculate that each increase of 2 percentage points in the daily mortality rate will cause about 50 percent reduction in the number of nymphs that survive to the adult stage (table 1). At 13 percent daily mortality, less than 1 percent survive to become adults. If we assume that adults require 17 days before they reproduce, an increase of 10 percentage points in average daily mortality will cause an 80 percent reduction in the number of adult females that produce at least 1 egg pod (table 1).

It is of utmost importance to understand that immediate effects of treatments do not necessarily have to be dramatic to bring about dramatic adjust-

ments in population density. A relatively subtle increase in the daily mortality rate can have dramatic consequences over a season. This can be illustrated by hypothetical examples of three different control tactics that currently are available. In figure 2, grasshopper numbers (N) are illustrated as a function of their initial number (N_0) and their daily survival rate (S) according to the relationship $N_d = N_0 (S^d)$, where d = age in days assuming day zero is the earliest day that a treatment can be applied.

Table 1.--Average percentage survival of grasshoppers as affected by average daily mortality rates during 35 days of nymphal development and 17 days as sexually-immature adults

Nymphs		Adult females	
% mortality per day	% that become adults	% mortality per day	% that lay eggs
3	34	5	49
5	17	15	10
7	7.9	25	2
9	3.7	35	0.4
11	1.7		
13	0.8		

Figure 2 also assumes for simplicity that on day 60, a killing frost terminates the infestation. Figure 2A assumes an infestation of 20 grasshoppers/unit area, a daily survival rate of 0.975, which is typical of stable populations, and no treatment applied. The total seasonal presence of grasshoppers can be calculated as the area under the population curve; that is as 630 "grasshopper days" (GHD). Figure 2B assumes that an insecticide bait treatment applied on day zero provided an instantaneous 50 percent kill. Assuming no subsequent change in the daily survival rate, the GHD for the season is 315, so about 50 percent reduction was achieved. Figure 2C assumes that a broadcast spray treatment applied 20 days later gave 100 percent kill. The result is quite spectacular but did not prevent 315 GHDs before treatment, so about 50 percent reduction was achieved. Figure 2D assumes that a bait treatment with a pathogen, *Nosema locustae*, applied on day zero reduced the average daily survival rate less than 4 percentage points (that is, to 0.9376) over the 60-day season. Results are not very spectacular. In fact, cursory inspection may not even detect such a subtle effect. Nevertheless, 315 GHDs were prevented so 50 percent reduction was achieved.

GRASSHOPPER CONTROL

Chemical control tactics.--Chemical insecticides CAN be applied as soon as an economic infestation begins to cause significant forage destruction (that is, when the majority of grasshoppers attain the 3rd nymphal instar). Chemicals MUST be applied before oviposition begins (that is, before about

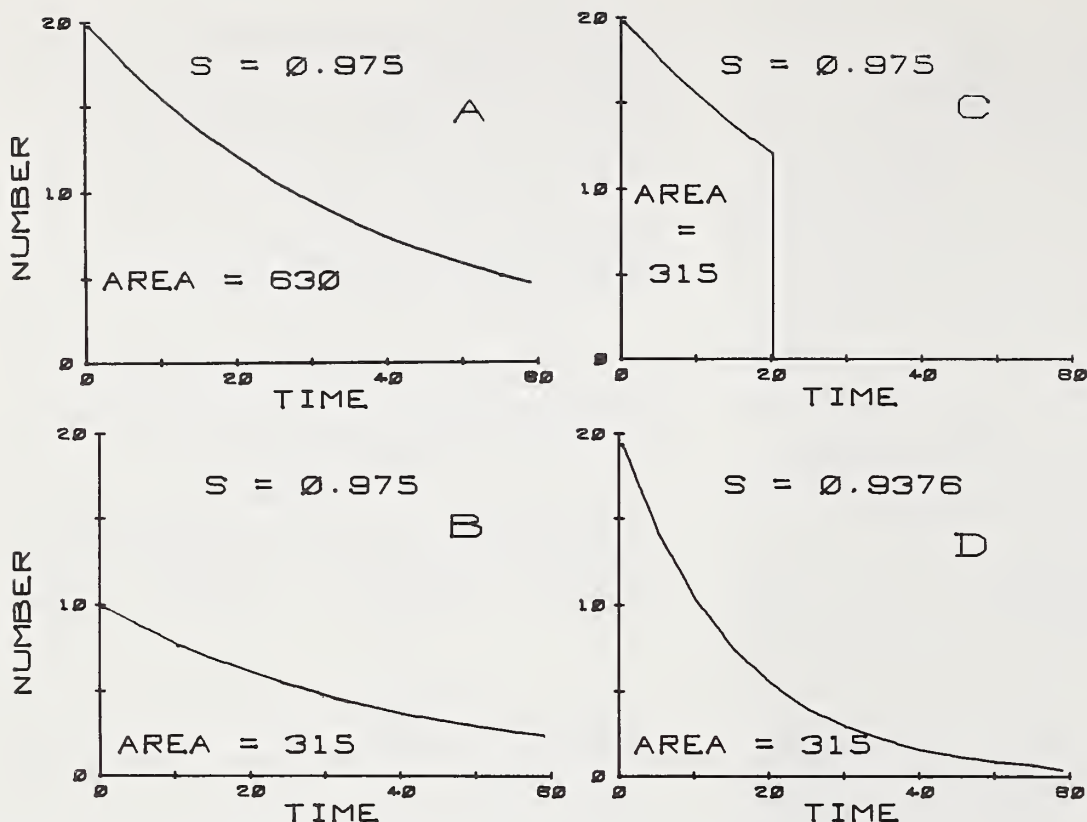


Figure 2.--Hypothetical examples of efficacy for 3 types of grasshopper control tactics that currently are available: A = untreated; B = insecticide bait; C = broadcast spray; D = *Nosema locustae* (see text for elaboration).

day 18 of the adult period) if one intends to prevent reinfestation for the next season. Thus, a total time frame of about 44 days (three 9-day nymphal periods plus one 17-day adult period) is available for control tactics.

At present, three chemical insecticides for broadcast spray applications and one for bait application are registered for control of grasshoppers on range. Economic thresholds have been estimated for spray treatments using carbaryl and malathion insecticides (Onsager 1984). Carbaryl is a relatively long-lasting insecticide. It functions both by contact and as a stomach poison and can be applied relatively early in the season. It was efficacious over the entire 44-day time frame, was most efficacious over an 18-day period applied to late 3rd, 4th, or early 5th instar nymphs, and provided the greatest absolute prevention of forage destruction (fig. 3). Malathion is a short-lived contact insecticide that functions best under hot, dry conditions. It seldom is applied before grasshoppers attain the late 5th instar stage and therefore is efficacious over only about a 21-day period. It had a very narrow window of peak efficacy, but gave control equal to carbaryl applied at the same time (fig. 3). Because malathion is considerably cheaper than carbaryl, it is nearly always preferred for late-season treatments. However, no treatment can compensate for forage that has already been destroyed, so early

treatments with either chemical are much more economical than late treatments. The third registered spray treatment is acephate. We do not have sufficient data to predict efficacy with the same degree of confidence as for carbaryl or malathion. However, it appears to be intermediate between malathion and carbaryl in mode of action and persistence. The cost in the past has been slightly less than malathion.

Insecticide bait provides a cheap, fast, and selective method for reducing grasshopper infestations. It is my personal opinion that the technology has been grossly underexploited. Experimentation has established that 0.5 to 1.5 lb of wheat bran bait/acre containing 2 percent carbaryl gave highly predictable reduction of grasshoppers (Onsager et al. 1980). The efficiency of that bait was only 16 percent, which led to recent experiments in which 0.15 lb of bait/acre containing 20 percent carbaryl gave equivalent results. A disadvantage of bait is that only about 75 percent of the grasshoppers were vulnerable, due to a combination of factors that included the molting process, feeding preferences, and chance. However, it should be apparent that 75% control is more than satisfactory in many situations.

Advantages of bait include a high degree of selectivity (that is, minimum adverse effects on non-target species), very low rates of toxicant

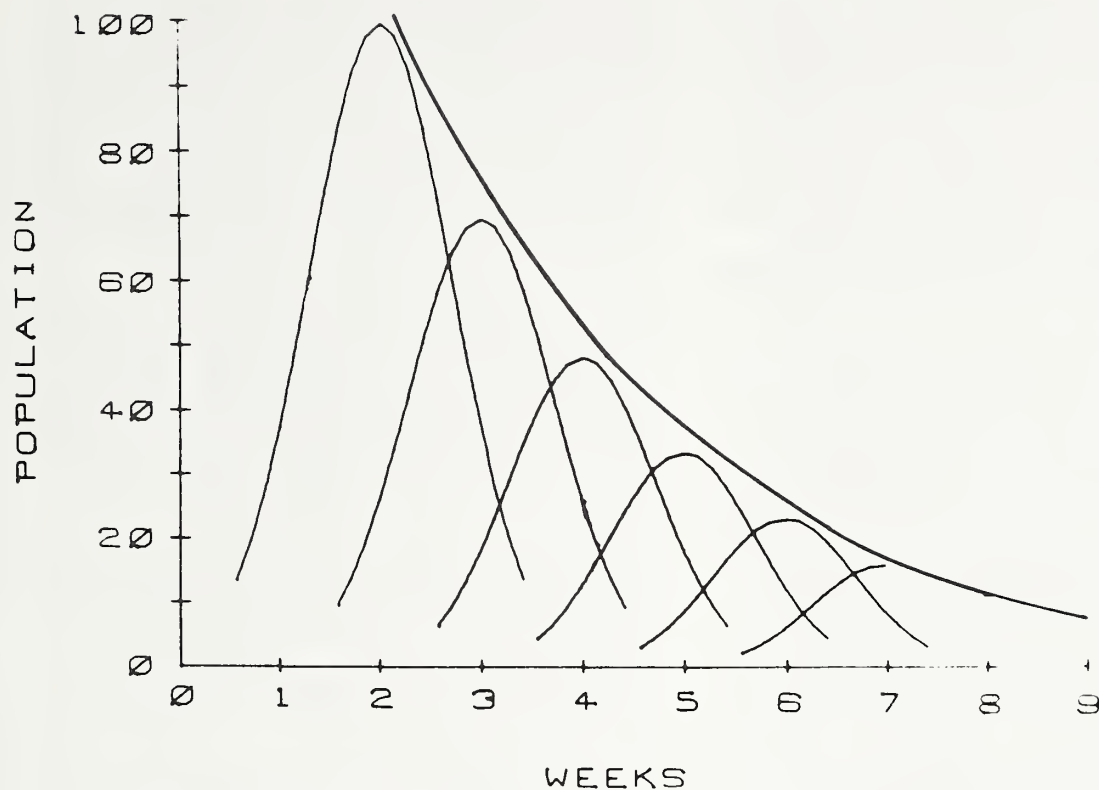


Figure 3.--Relationship between stage of grasshopper development at time of treatment and percent reduction in forage loss following treatment with carbaryl (C) or malathion (M) applied to infestations that averaged 8 or 32/m² at the beginning of the 4th nymphal instar.

(that is, 6 percent of dosages applied in sprays), very low rates of diluent (that is, as little as 0.15 lb of carrier/acre), a surviving reservoir of grasshoppers for beneficial organisms that prey upon them, and a tolerance for weather conditions that would preclude application of chemical sprays. I grant that bait applications involve more logistics problems than spray applications, and adequate application technology is not generally available at this time. Nevertheless, if ranchers really do become serious about long-term intensive management of invertebrate grazers as well as vertebrate grazers, then I firmly believe that bait treatments will play an important role in management of grasshoppers, and that demand for such treatments will stimulate an industry to supply them.

Biological control tactics.--*Nosema locustae*, a protozoan parasite of grasshoppers, was developed by USDA/ARS as a biological tool for long-term suppression of grasshopper populations. While its natural epidemiology in grasshoppers is well understood (Henry 1972), its performance in large-scale field tests since 1975 has been neither consistent, nor spectacular, nor easily quantified. We are still learning what to look for and how to assess the subtle effects of this suppression tactic.

Complications include the facts that different grasshopper species respond differently to infec-

tions, and that different scientists and ranchers respond differently to results of experimental treatments. Among tolerant grasshopper species, about 50% of infected individuals will survive for more than 4-6 weeks (Henry et al. 1973). These survivors are bad if the only objective is to immediately suppress grasshoppers, but they are good if one objective is to generate inoculum to infect the next generation. Among susceptible grasshopper species, numerous individuals succumb relatively quickly before the infection can be diagnosed (Henry et al. 1973). These casualties are good because we want some grasshoppers to die, but they are bad if a scientist is expected to prove cause of death through postmortems in order to achieve credibility.

At the risk of appearing to be both inept and prejudiced, I will declare that in each of 5 large field tests of *Nosema locustae* in which I have participated, something important has gone wrong. Problems have included a fungus epidemic, deterioration of bait due to default of a legal contract, mass migration of grasshoppers that destroyed plot integrity, no aircraft available at the proper time for treatment, and commercial application equipment that was impossible to calibrate correctly. Nevertheless, in 2 of 3 experiments that I consider to have some "salvage" value, grasshopper infestations in *Nosema* treated plots abated over 1, 2, or 3 seasons while untreated infestations remained high.

Therefore, intuition tells me that Nosema locustae can play a role in future management of grasshoppers on rangeland, but that role has not yet been clearly defined. It certainly will not provide a quick cure for severe problems, and the prevention of such problems is not a significant part of current management strategy. Perhaps intensified use of predictive modeling could increase the importance of preventive tactics, but, at present, it appears that Nosema locustae has high utility only in sensitive areas where chemical insecticides are prohibited for environmental reasons.

Approximately 200 spp. of insects, mites, and nematodes are parasites or predators of American grasshoppers (Rees 1973), but no grasshopper control tactic that utilizes deliberate manipulation of parasites or predators is currently operational. The closest we have come was a large test of bait mixtures containing carbaryl for some quick kill and Nosema locustae for long-term suppression (Onsager et al. 1981). Midseason mortality progressed more rapidly than could be accounted for by the action of the pathogen. Indirect evidence indicated that the insecticide bait, by selectively reducing the grasshopper population, exposed the survivors to more intensive parasitism and predation from beneficial insects that were not affected by the treatment. This tactic could have utility in an IPM strategy but we need more research to ascertain whether such enhancement of the parasite-predator:prey ratio is consistently possible.

One of the reasons that parasites and predators fail to maintain low grasshopper populations is that these creatures are subject to attack by their own parasites and predators. For example, in a study of Blaesoxipha spp. parasites by Rees and Onsager (1982), the average longevity per adult female parasite was only 3-5 days, which prohibited the parasites from attaining reproductive maturity.

Manual suppression of robber fly predators in experimental plots by about 38 percent increased the incidence of parasitism among grasshoppers by about 260 percent (Rees and Onsager 1985). Ironically, many species of robber fly are beneficial predators of grasshoppers (Joern and Rudd 1982, Dennis and Lavigne 1975) but in our experiment, about 88 percent of the robberfly population was composed of species that prey predominantly upon flies, including beneficial parasitic flies, rather than upon grasshoppers. Therefore, the robber flies actually enhanced survival of grasshoppers.

Cultural control tactics.--Mulkern (1967) reviewed 145 references pertaining to food selection by grasshoppers. In spite of general agreement that many species are highly discriminating in their selection of food, relatively little research effort has been attempted to exploit that phenomenon. Hewitt (1968), Hewitt and Blickenstaff (1969), and Harvey and Hackerott (1976) reported sources of grasshopper resistance among a variety of forage crops, but no attempt was made to capitalize on this information through a breeding program. More recently, Hewitt et al. (1982)

identified several sources of resistance or tolerance to grasshoppers among alfalfa cultivars being selected for rangeland interseeding. In subsequent studies (Hewitt and Berdahl 1984), the rate of forage consumption varied by 200-fold among selected alfalfa cultivars, and heritability was sufficient to warrant a breeding effort to increase resistance to grasshoppers. These results indicate high potential for future utilization of host plant resistance to grasshoppers, but this control tactic obviously is not operational at present.

The impact of different grazing strategies on grasshopper populations is not clear, but the literature contains clues as to possible relationships. There is agreement that grasshopper species diversity tends to decline as habitats are significantly disturbed through overgrazing (Joern 1979, Pfadt 1982) or mechanical disruption (Anderson 1964, Hewitt and Rees 1974). However, many of the species that survive such disturbances are notorious for their capacity to increase to outbreak proportions. Thus, grasshoppers were reported to be unusually abundant during dry seasons in heavily grazed pastures of mixed grass prairie in Oklahoma (Smith 1940), tall grass prairie in Kansas (Campbell et al. 1974), and fescue grassland in Alberta (Holmes et al. 1979). In contrast, on short grass prairie of Colorado and Arizona, where low plant biomass apparently can limit grasshopper biomass, grasshoppers were most abundant in ungrazed or lightly grazed pastures (Capinera and Sechrist 1982), in relatively undisturbed sites (Pfadt 1982), and during years having normal or above-normal precipitation (Nerney 1958). Pepper (1955) stated that "Montana rangeland which is well managed from the standpoint of grass production does not develop a grasshopper problem." There is a question, however, of whether good management prevents grasshopper problems or whether the absence of a grasshopper problem simplifies management. In a Montana study by Anderson (1964), some areas that appeared habitable simply were not occupied by grasshoppers. Grasshopper species abundance could be not correlated with density of host plants, and grasshopper density could not be correlated with abundance of host plants. Rather, grasshopper populations generally were inversely proportional to plant height and amount of cover. Most species occurred where the percent total foliage cover was less than 40 percent, and area dominated by big sagebrush or greasewood never harbored grasshopper populations greater than 1/yd².

There is excellent documentation of grasshopper outbreaks on the western range even under pristine conditions (Riley et al. 1878). Bird (1961) postulated that overgrazing by bison used to favor such outbreaks. If so, I can conceptualize grasshoppers as a natural mechanism to prevent repetitive overgrazing. Recovery from severe grazing would be encouraged if energy and nutrients in subsequent crops could decompose in place rather than be assimilated, concentrated, and carried elsewhere by large, free-roaming herbivores. Grasshoppers do not significantly inhibit production of forage (Hewitt 1979) but are effective in reducing it to litter (Mitchell and Pfadt 1974). Therefore, grasshoppers undoubtedly

could have become sufficiently competitive to have encouraged bison to take their overgrazing to greener pastures.

In summary, it appears that any range management practice that significantly opens up the plant canopy, either temporarily or permanently, will tend to improve the microhabitat, either temporarily or permanently, for important pest species of grasshoppers. Decreased relative humidity, increased temperature, and increased solar radiation all will tend to enhance grasshopper development, and all will tend to debilitate important grasshopper pathogens. Important parasites and predators may be deprived of cover. There are tools available to mitigate such consequences, but the situation should not be encouraged unless one is willing and able to intensify management in order to deal with it.

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THE STATUS OF IPM STRATEGIES FOR CONTROLLING GRASS BUGS INFESTING INTRODUCED GRASSLAND MONOCULTURES

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ABSTRACT

The general situation regarding grass bugs in grass monocultures, and the status of IPM strategies are discussed. The management strategies considered are: control by chemicals, plant resistance, burning, grazing, planting heterocultures, and biological control. Chemical control has been effective and economical when properly done, but additional research with new materials and rates of application is needed. Undergrazing and rest rotation have resulted in a build-up of some bug populations. Thorough, short-term, intensive grazing has controlled some bugs as has thorough fall burning. In the future, methods of rangeland improvement by debris-in-place management or seeding mixtures of range plants should be investigated rather than the establishment of grass monocultures. Traditional IPM biological control methods appear to have good potential in rangelands, but little research has been done on this management strategy to date.

INTRODUCTION

The purpose of this paper is to inform entomologists and others interested in range management and improvement about the status of IPM strategies for controlling grass bugs--mostly Labops hesperius Uhler, Irbisia brachycera (Uhler), and Irbisia pacifica (Uhler), in range grass monocultures. To accomplish this purpose, the history of the introduction of wheatgrasses and their infestation by grass bugs is reviewed. Grassbug biology and the status of six management control strategies are summarized. Each management strategy is examined in terms of its utility.

GENERAL IPM SITUATION REGARDING GRASS BUGS IN GRASS MONOCULTURES

According to Hagen (1982) crested wheatgrass, Agropyron desertorum (Fisch. ex Link) Schult, has been grown in Nebraska since the late 1930's. Dillman (1946) discussed the early introduction of crested wheatgrass in North America.

L. hesperius was first described in 1872 from specimens collected in Colorado and Montana (Markgraff 1974). However, it was widely reported on crested wheatgrass shortly after introduction of the latter. Details of some of these historical events were reported or reviewed by Knowlton (1945), Denning (1948), Brandt (1966), Ostlie (1979), and Haws and Bohart (1985).

Studies of life and seasonal cycles, behaviors, distribution, hosts, and other basic biological information concerning L. hesperius have been reported by investigators in several states (Coombs 1984; Fuxa 1975; Fuxa and Kamm 1976a, 1976b; Haws

1972, 1975, 1979; Haws et al. 1973, 1978, 1982a, 1982b; Jensen 1971; Kamm 1979; Kamm and Ritcher 1972; Knight 1982; Ostlie 1979; Paraqueima 1977; Spangler 1984; Todd 1974; Todd and Kamm 1974).

Some ranchers and range conservationists are now applying several grass bug control strategies themselves (such as application of insecticides, burning, or grazing) or they are requesting assistance from the various Extension Services. The national program of the Animal and Plant Health Inspection Service (APHIS) (gathering, storing, and electronic distribution of information) is increasingly prompt in reporting and distributing pest information and control strategies. The APHIS program is operational in most states. Agencies are cooperating in informing each other about grass bugs with improved efficiency. Most Utah counties are equipped to take advantage of the APHIS program with their local computers that facilitate rapid distribution of information about grass bugs and their control throughout the state.

A recent survey taken to get information for this paper indicates that five of the western states are now continuing research concerning grass bugs of monocultural grasses, as far as it was possible to determine. There are many problems that remain to be solved. Examples of these problems include: (1) improving the quantity and quality of the wheatgrass forage and seed by insect control, (2) collection and identification of other insects and their roles in monocultural grasses, (3) determination of the impacts of insects and weeds in free-ways and road-side grasses on rangeland and domestic plants, (4) development of new registered pesticides and more economical methods of applying them for range insect control, (5) provision of new biological/climatological data about range grass pests to assist other disciplines in the production of more accurate development and economic predictive models, and (6) determination of combinations of plants that provide optimum habitat conditions for beneficial arthropods and other animals to create a biological balance and improved quantities and quality of range forage.

PRESENT STATUS OF IPM STRATEGIES AND FUTURE NEEDS

Chemical Control

Because of costly losses associated with grass bugs infesting monocultures, chemical controls of L. hesperius were attempted even before details of the life cycle were known (Brandt 1966; Jensen 1971; Lindsay 1970). As life history of grass bugs became at least partially known, the investigations of chemical control continued. Control of L. hesperius by chemicals often was not the most desired approach due to the relatively low income from rangeland grasses compared with the costs of chemical control (Todd and Kamm 1974; Haws 1975; Brindley and Osman 1978; Haws et al. 1978, 1982a; Huddleston and Smith 1982; Coombs 1984).

Tests of chemicals in small plots and in practical field applications established malathion as an effective, economical control in some areas, and contributed to understanding of important aspects of toxicology (Haws 1979; Knight 1982; Huddleston

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and Smith 1982; Haws 1982a; Osman 1979). The 1984 Utah control recommendation was 8 ounces (AI) ultra low volume (ULV) malathion per acre (0.4 ha) at temperatures above 65 degrees F (18 celsius). The malathion should be applied after all eggs have hatched [3-4 instar, approximately 28,000 growing degree hours (GHD celsius)], but before the females have laid their eggs. If more than one year of control results from a single application of malathion, control is usually economically feasible (Glover 1978, 1982). When the bugs are effectively controlled before the females lay their eggs, practical experiences indicate that, because the bugs reinfest or migrate into fields slowly, it may not be necessary to control them again for several years. Application of the ULV formulation by helicopter or fixed wing aircraft generally was effective in distribution of the toxicant. Our ground sprayer applications of emulsifiable malathion have also resulted in good control.

In 1974, 960 acres of range grasses in Morgan County, Utah were sprayed with 8 ounces of ULV malathion by helicopter. This application remained effective for at least four years, and the first necessary retreatment was 1984. Nearby ranches that were not sprayed in 1974 have remained infested by the bugs, and have been used in various studies (such as control by burning) and as sources for collecting bug eggs for laboratory studies ever since 1974.

In 1982 extensively damaged fields of crested wheat and intermediate wheatgrass were sprayed with 8 ounces of malathion by fixed wing aircraft in Beaver County, Utah. Cost of the control was \$1,921. The income from that field (that the ranchers had expected to be practically zero) for the first year through sales of AUMs was \$2,100. In addition the rancher grazed 90 head of yearling cattle on the ranges for one month. In 1983 and 1984 the bug population on the sprayed fields was near zero, while the bugs were abundant in nearby roadsides and untreated fields.

Early detection of an infestation is essential. In Utah grass bug eggs hatch as snow melts, and the nymphs begin to feed as soon as they hatch. This can require inspection from late March or early April through May, depending on elevation and GHD. Fortunately, the total infestation intensity can be determined early because the bug population has only one generation per year. Close examination of the grasses may reveal either the bugs or their damage (whitish or yellowish feeding spots on the leaves). Young nymphs are difficult to see or capture, but later instars (3-5) and their damage are easier to see and are useful in determining the intensity of an infestation. The general tendency is that much damage occurs and females lay eggs before range managers become aware of or attempt to control a problem.

Use of growing degree hours to determine when various instars of the bugs are present has been useful. The fact that L. hesperius develops early in the season allows for its control when it is mostly out of phase with some of the beneficial animals (birds, etc.) that we desire to protect from insecticides. Fortunately the grass bugs are

easily destroyed by the malathion, and this chemical has a very short residual effect. We have not studied the effects of the application of malathion for control of grass bugs on beneficial insects.

There is a need for more research with chemical controls. Some research suggests rates of application less than 8 ounces per acre may effectively control grass bugs, but these results have not been verified. Malathion has the limitation of not being effective at relatively cool temperatures. Most control of grass bugs in the colder regions of the west usually is done in early spring during cool weather. Malathion's short duration of effectiveness is both an advantage and a disadvantage. Testing and registration of other chemicals for use in control of grass bugs is needed. Pydrin was tested for grass bug control (Coombs 1984) in 1983. It showed better residual action and was more effective than malathion at colder temperatures, but it is not registered for general use at this time.

Grass Bug Control by Range Plant Management

The consensus of a Utah interdisciplinary research team was that the origin of problems with Labops probably was related to range grass management (planting monocultures, undergrazing, etc.). Possible changes in management of ranges and live-stock were among the first strategies investigated. Logic supporting the strategy of planting heterocultures instead of monocultures is supported by data suggesting fewer grass bugs have been found in mixed communities of forbs, shrubs, and grasses than in adjacent monocultures of crested wheatgrass (Ostlie 1979). Differences in the kinds and numbers of insects collected in native ranges and in monocultures, together with common knowledge and experiences with beneficial insects in other crops, suggest that beneficial impacts of insects can be increased by providing proper food and habitat for them.

Jensen (1971) concluded that the best insurance against heavy Labops infestations is a balance of plants in reseeding range communities. Mixed plant communities promote insect diversity and thus develop a biological balance that will provide continuous food and favorable habitat for beneficial insects. Parasites and predators are particularly important components of an undisturbed ecosystem (Spangler 1984). They keep many injurious insects in check. Promoting beneficial insects usually involves the inclusion of pollen and nectar sources, and plants that provide protection from the elements. We do not know enough yet about insect/plant relationships to recommend these favorable combinations of plants.

Spangler (1984) studied sap-feeding and predatory insects in pure (manipulated) stands of grasses compared with mixtures of native plants, including sage. His data suggest that big sage was more important than crested wheatgrass in determining faunal structure. Fewer sap-feeding insects were found where the grass was interplanted with plants that were taxonomically unrelated than in the monocultures. Lower levels of insect predators

were found in the reseeded areas. There was a trend from a homopteran-dominated fauna in a mixed range to a mirid-dominated one in monocultures.

Debris-in-place management (in which large plants such as juniper trees or sage are removed, but some grasses, forbs, and shrubs remain) provides habitat and food for many insectivorous animals (birds, lizards, parasites, and insect predators). The studies of Ostlie (1979), in which the numbers and behaviors of L. hesperius in a monoculture of crested wheatgrass were compared with those in a native range, suggest that a mix of range plants might also include plants that are repugnant to insects (perhaps sagebrush) or that are otherwise unfavorable to them.

Society has learned to manage and increase the productivity of many crops by growing them as monocultures (corn, wheat, potatoes, etc.). Inasmuch as we already have millions of acres of monocultural grasslands, we need to learn how to manage them for pest control. But in the future, some problems with range insects probably can be avoided if the steady state of ecological balances existing in some native rangelands can be imitated.

The agricultural practice of strip cropping to preserve beneficial insects is a feasible practice in many range renovations situations. Islands or peninsulas of native vegetation can often be left as a source habitat for beneficial insectivores so that they can help control insects in nearby introduced range seedlings.

Black Grass Bug Control with Plant Resistance

Differences in resistance of grasses to L. hesperius between and within genera of grasses, and among clones and their crosses have been demonstrated (Asay 1984; Campbell et al. 1984; Hansen et al. 1984; Haws et al. 1978 and 1982a; Hewitt 1980; Windig et al. 1983).

Physical/morphological characteristics and chemical composition of grasses showing different amounts of damage by Labops have been investigated (Campbell et al. 1984). The trichomes of grasses differed considerably in size and density, as they did on grasses produced in the field and greenhouse (Ling 1982). Leaf pubescence appeared to be associated with resistance of Agropyron to nymphs of L. hesperius in the second and third instar, but not to adults. It was concluded that these morphological characteristics were not completely reliable indicators of plant resistance to Labops. Campbell and others (1984) have published a review of literature related to grass resistance to Labops.

Windig et al. (1983) utilized pyrolysis mass spectrometry (Py-Ms) with discriminant analysis to develop chemical profiles of grasses as related to Labops damage. Their results indicate significant differences in amount of grass bug damage to parent breeding lines and crosses (Haws and Bohart 1985). Their results also suggest that senescent leaves provided better material for testing resistance than green leaves.

The need to field test so-called resistant selections in various geographical locations is illustrated by results of Hewitt (1980) which indicated that intermediate wheatgrass is tolerant to Labops. Utah results in nearly all tests indicate that intermediate wheatgrass is one of the most susceptible grasses to Labops damage. Intermediate wheatgrass frequently has more Labops than crested wheatgrass (Haws and Bohart 1985), and sustains damage when bugs are present (Hansen et al. 1984; Todd and Kamm 1974; Higgins et al. 1977). Hansen et al. (1984) reported that crested wheatgrasses and their hybrids, along with intermediate wheatgrass, were the most susceptible grasses, while western wheatgrass was the least preferred. They noted that reports of host plant preferences by different persons often are conflicting. For example, Hewitt (1980) concluded that intermediate wheatgrass was more resistant to Labops than western wheatgrass or bluebunch wheatgrass. Orchard grass (Dactylis glomerata L.) and reed canarygrass (Phalaris arundinacea L.) usually sustain little damage by black grass bugs in Utah tests (Hansen et al. 1984; Windig et al. 1983), but Todd and Kamm (1974) list orchardgrass as a host. Campbell et al. (1984) have reviewed other literature concerning grass resistance to Labops.

It can be concluded that relatively few grasses show definite resistance that might be incorporated into new varieties. There are many new entries available for testing. The potential of using resistant grasses as a management strategy was discussed by Asay (1984).

Black Grass Bug Control by Egg Destruction: Grazing and Burning

Todd and Kamm (1974) proposed that removal of straw by burning or grazing were feasible control strategies. They found an average of 7 nymphs in a burned area compared with 92 in a nonburned one.

Information from studies of accidental and controlled burns (Coombs 1984; Huddleston and Smith 1982) suggests that, since grass bugs migrate and reinfest fields slowly, thorough burning of pastures in the fall destroyed most eggs and resulted in lower grass bug populations for several years. A propane burner we tested destroyed grass bug eggs, but this operation was not economical. In a spring burn in Utah, many L. hesperius nymphs survived by hiding in cracks in the soil while the fire passed over them.

During 1981 a rancher burned part of a field of intermediate wheatgrass in Morgan County, Utah (Coombs 1984). The number of bugs in thoroughly burned regions was reduced to almost zero. The bugs moved very slowly from the nonburned areas into the burned areas, only about 25 feet during the summer. Also, it has been observed that it takes several years for the bugs to invade new seedlings of grass, and that the bugs move slowly as they spread from infested areas into contiguous pastures that were not previously infested. The principle of controlling bugs by grazing is the same as that for burning--destruction of the eggs in the fall. The success depends on the thoroughness of grazing. Undergrazing is a major factor in

facilitating outbreaks of grass bugs. Serious infestations of L. hesperius are rarely found where litter has been removed by grazing. Both in burning and grazing, islands of grass that are not removed often provide enough eggs to reinfest an area. Hagen (1982) found that removal of grass hay reduced populations of L. hesperius. Thus there is a consensus among investigators that removal of litter in the fall by grazing, burning, or haying reduces bug populations.

Only a small percentage of the female Labops have functional flight wings. Irbisia bugs may present a different problem than Labops because Irbisia fly and appear to be more mobile than Labops. The principle of egg removal for control should apply to Irbisia, since it often is found in the same habitat as Labops, but Irbisia may reinvade fastest.

Control by grazing is likely to be successful only where livestock can be forced to feed by being fenced in, or where the pastures are isolated and no other acceptable feed is available. A few ranchers have reduced grass bug populations enough by thorough grazing that they have not had to apply insecticides for grass bug control. These experiences need to be publicized among range managers and users. The need for supplementary feeding during times livestock are being forced to clean up field litter needs to be investigated.

There must be sufficient litter to sustain a thorough burn if this control method is to be effective. Even if some islands and a few bugs are left after a burn, the bug populations can be greatly reduced by burning. It may be practical and economically feasible to use a ground sprayer to apply an insecticide to the nonburned areas to further reduce an infestation of bugs. The impacts of burning on wildlife and insect predators and parasites have not been studied, but they should be.

Black Grass Bug Control by Methods of Clearing Rangelands and Establishing Introduced Grasses: Monocultures vs Heterocultures

Large acreages of rangeland have been cleared of practically all trees and shrubs by chaining, burning, or use of herbicides so monocultures of grasses could be planted or so native grasses could grow better. Little attention has been given to populations of insects or larger animals (many of them insectivores) before and after such operations.

In order to compare the relative abundance of grass bugs in a monoculture versus an adjoining range containing a variety of plants, Ostlie (1979) established circles of pit traps, with half of the traps in each habitat. There were clearly more Labops in the monoculture (38.5/trap) than in the heteroculture (9.7/trap). Bugs released in the center of the trap circles moved away from the heteroculture. The movement appeared to be away from sagebrush.

Practical observations of range conservationists and the limited research data available suggest

that there are fewer pest insects and less loss of forage in heterocultures than in monocultures. In future range improvement practices it would be well to consider debris-in-place management in contrast to complete removal of native plants and planting pure grass monocultures.

Biological Control

A thesis by Araya (1981) represents the only attempt at USU to investigate biological control as an IPM strategy. Araya swept insects from grass ranges, put them in cages, and observed the predation that occurred. He then caged the individual species of predators (including spiders) with observed insect prey species and observed the quantity of consumption. He also caged predators with a mixture of prey species to see if predators selectively chose their prey. Araya limited his study to predators. He concluded that damsel bugs are important predators of several range pests, especially leafhoppers, but they also fed on immature mirid nymphs, including Labops. Spiders generally are opportunistic feeders and they were among the most effective predators observed.

During laboratory rearing of Labops (Haws et al. 1978), it was discovered that eggs in stems of Poa bulbosa were infested by small hymenopterous parasites. Coombs (1984) found a nematode infesting a female Labops. A tigerbeetle found in a field infested with grass bugs evidently had been feeding on grass bugs (Haws 1972). Knight (1982) reported two parasites in Irbisia spp., in Nevada, but neither appeared to be controlling the bugs.

Many predators and parasites are present in rangeland grasses, but much remains to be done in identifying the kinds and numbers present, learning the biologies, and finding ways of protecting them. Methods of modifying present range management procedures or of developing new ones to promulgate or protect predators and parasites have hardly been considered. We also need to expand our knowledge of what the impacts are on beneficial insects and wildlife when we apply strategies of chemical control, grazing, and burning to control grass bugs.

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RANGE INSECTS - PESTS AND BENEFICIALS

Jeff B. Knight

ABSTRACT

Insects that are known to occasionally injure range, but for which management or control strategies generally are lacking, include leafhoppers, mealybugs, white grubs, caterpillars, and harvester ants. Beneficial insects have been studied or utilized primarily for control of weeds and major insect pests on range. However, little is known about natural enemies of occasional insect pests of range.

INTRODUCTION

This paper discusses pests and beneficial insects in the sagebrush ecosystem other than grasshoppers, Mormon crickets, black grass bugs, and their associated predators and parasites.

Many of the following pests were extensively discussed by Hewitt, et al. (1974). These minor pests occur on a limited number of acres, and outbreaks are often undetected or detected late in the outbreak. This late detection is primarily due to the irregularity of sampling, and lack of standard methods for sampling and cataloging finds. Also, the initial observers of these infestations generally lack any training in recognizing these types of pest problems.

The above problems are being approached with the BLM, and National Forest Service in Utah requesting training sessions in range insect identification, sampling, and management. Programs like this should be encouraged in other parts of the region.

Problems also exist in making control recommendations for these pests. Even if a chemical is registered for the site and pest, very few if any of these pests have damage thresholds.

PEST GROUPS

Homoptera

Leafhoppers represent a very diverse group of occasional range grass pests. Studies have shown as many as 28 genera occurring on various grasslands (Blocker and Reed 1976; Knight 1982). One genus (Dikeneura) has been reported causing damage to range grass, and extremely high numbers of an unidentified leafhopper (900 per sweep) have also been observed (Knight 1982). This group also has the potential for transmitting a variety of diseases. Nothing however, is known on the impact or management of this group on rangelands in the sagebrush ecosystem.

Aphids and mealybugs have been observed in high numbers on several range seedings. The failure of one seeding in northwest Nevada has been attributed

to mealybugs (personal communication: R. W. Lauderdale, Emeritus, University of Nevada, Reno).

Hemiptera

The genus Leptopterna (a plant bug) is very common on a number of grasses in the sagebrush ecosystem. It appears to feed both on the grass seed heads and leaves of grasses. Many other hemipterans (especially the mirids, lygaeids, and pentatomids) feed on a wide variety of our range plants.

Coleoptera

The larvae of scarabs or June beetles commonly cause extensive damage in turf, but 2 genera, Phyllophaga and Paracotalpa, have been reported causing damage to range grass in the U.S. (Hewitt et al. 1974; Haws 1982). Another species, Costeultra zealandica (White), causes extensive problems on range grasses in New Zealand. A variety of controls are being developed for this pest. This includes resistant varieties, (Farrell and Sweeney 1974) grazing, (East and Willoughby 1980) and chemicals including synthetic pyrethroids (Henzell and Lauren 1978). The lack of visibility of the underground larval stage of click beetles or wireworms probably accounts for the scarcity of reports of these insects on grasslands in the sagebrush ecosystem. This group and the false wireworms (Tenebrionidae) are probably most important in the establishment of new seedings where the larvae feed on germinating seeds.

The larvae of billbugs (Sphenophorus sp.) also do extensive damage to turf and have caused severe damage on range grasses in test plantings (Haws 1982). Currently work is underway at Utah state University by the ARS to develop varieties resistant to this pest.

Lepidoptera

Sod webworms have been reported damaging grasses in other range ecosystems, but as of yet there have been no reports of severe damage to grasses in the sagebrush ecosystem.

Many lepidopterous larvae, including fall webworms and tent caterpillars, attack shrubs in the Great Basin. One such species, the sagebrush defoliator (Aroga websteri (Clark)), attacks sagebrush and can kill or weaken stands of sagebrush. These outbreaks are usually erratic and usually cover only small acreages. This species may be regarded as either a pest or beneficial depending on how the land is being managed.

Diptera

Two groups of flies warrant mentioning due to their potential as pests. Again little is known of their impact on grasses and forbs on rangeland. The fruit flies or chloropids commonly feed on seed-heads and meristematic tissue and have been reported causing several abnormalities in grasses. Leaf-mining flies occur on numerous range plants, primarily forbs.

Hymenoptera

Harvester ants are a widespread group containing several important pest species. The literature on these ants was extensively covered by Lavigne and Rogers (1974).

In recent years, requests for management strategies for harvester ants in the Great basin have remained at a moderate level. Since the loss of chlorinated hydrocarbons, there have been no chemicals that have given effective control. Recently, an American Cyanamid product called Amdro® has been registered for harvester ant control on grassland and nonagriculture land. This compound has proven successful on small acreages and may provide the small private landowner with some relief from this pest. The high cost of this compound may be a problem for larger land management agencies.

Two groups of plant feeding Hymenoptera other than ants have been shown to significantly infest range grasses in recent years. The first, a sawfly in the genus *Pachynematus*, has in recent years defoliated 5,000 acres of crested wheat in eastern Nevada (Haws 1982). Even though the managers of the pastures were notified of the problem, nothing was done to control the infestation. The reasons given for this attitude were; (1) costs of control, and (2) the problem of the application of pesticides on public lands.

The other group is the stem sawflies. The larvae of this sawfly lives in the centers of the grass culms. No severe damage has been observed from the sawfly in natural stands of Basin Wildrye even though a high percentage of the culms were infested. This sawfly could have a significant impact on seed production but this has yet to be shown.

Beneficials

Predators and parasites play an important role in any IPM system. This role includes the use of biological agents to control weeds. Predators, parasites, and diseases of the major insects pests, (grasshoppers, Mormon crickets, and black grass bugs) have been or are currently being determined and put to use in IPM systems for these pests. The impact of many of these organisms will probably be very similar to the same or similar organisms occurring in agricultural systems.

Habitat management (especially increasing species diversity) plays an important role in the management of predators and parasites. Haws (1982) has shown that by increasing the percentage of sage in crested wheatgrass pastures, populations of *Labops* were decreased and predator populations increased.

The control of weeds with biological agents (especially insects) offers an alternative means of controlling a number of range weed problems. Where the potential for the introduction of these agents exist, every effort should be made to do so. The method of control offers the potential of a long term - low cost control. The list of biological control agents available for introduced and natural weeds grows longer each year (Table 1).

Table 1.--Some biological control agents and their host currently being released

<u>Carduus nutans</u> L. (Musk Thistle)
<u>Rhinocyllus conicus</u> Froelich
<u>Trichosirocalus horridus</u> (Paazer)
<u>Centaurea diffusa</u> Lam. (Diffuse Knapweed)
<u>Pelochrista medullana</u> (Stgr.)
<u>Sphenoptera jugoslavica</u> Obenerger
<u>Centaurea solstitialis</u> L. (Yellow Starthistle)
<u>Urophora sirunaseva</u> (Hering)
<u>Cirsium arvense</u> (L.) Scop. (Canada Thistle)
<u>Ceutorhynchus litura</u> (F.)
<u>Urophora cardui</u> L.
<u>Cirsium vulgare</u> (Savi) Tenore (Bull Thistle)
<u>Urophora stylata</u> L.
<u>Euphorbia esula</u> L. (Leafy Spurge)
<u>Oberea erythrocephala</u> Mulsant
<u>Hypericum perforatum</u> . (Klamathweed)
<u>Zeuxidiplosis giardi</u> (Kieffer)
<u>Linaria dalmatica</u> (L.) (Dalmation Toadflax)
<u>Calophasia lunula</u> (Hufnagel)
<u>Silybum Marianum</u> (L.) (Milk Thistle)
<u>Rhinocyllus conicus</u> Froelich
<u>Tribulus terrestris</u> L. (Puncturevine)
<u>Microlarinus lareynii</u> (J. du Val)
<u>Microlarinus lypriformis</u> (Wollaston)

FUTURE RESEARCH

Three areas of study show potential for increasing range production and further understanding the impact of insects on rangeland. The first is the impact of insects on the production of seed in range grasses under non-cultivated situations.

Determination of the distribution of insects in the sagebrush ecosystem and the cataloging of these insects is also an area which needs further research. At this time some effort is being made to achieve this goal. Currently three states are reporting rangeland insect problems on the APHIS PPQ Pest Computer Network, and work has been undertaken to catalog insects associated with shrubs in the Western Region by Dr. Austin Haws at Utah State University.

The final area which could lead to increased range production would be the effect that insects have on the establishment of range seedlings and the revegetation of burns, mines, etc. From initial studies in Nevada, several groups of insects including wireworms and false wireworms could have a significant impact on developing plant seedlings and germinating seeds (Haws 1982).

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WILDLIFE AND PEST CONTROL IN THE SAGEBRUSH ECOSYSTEM: BASIC ECOLOGY AND MANAGEMENT CONSIDERATIONS

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ABSTRACT

The vast sagebrush (*tridentatae*) rangeland ecosystem of western North America encompasses a variety of growing sites and a complexity of intermixed vegetation. Condition classes vary from very poor to good/excellent. Those factors influence the species and abundance of the associated animal life. Few wild vertebrates are true sagebrush obligates; 3 species of mammals, 4 birds, and possibly 1 reptile. However, many other vertebrate species inhabit the ecosystem, including at least 89 species of mammals, 100 birds, and 41 reptiles and amphibians. Sagebrush communities are inherently less productive per unit area than more mesic ecosystems, but sagebrush is so widespread and relatively free of disturbance that it is one of the most important wildlife habitat types in the west. Sagebrush provides critical winter range for mule deer and pronghorns. Deer cannot survive on sagebrush alone but can utilize up to 50% in their diet. Healthy sagebrush communities are characterized by a heterogeneous vegetative cover of vigorous sagebrush, perennial grasses, and forbs, in which insects are usually held in check by natural controls. Grasshoppers at low population densities are a significant functional component of healthy rangeland. Grasshopper feeding activity stimulates plant growth and creates litter which builds soil and conserves moisture. The insects provide a readily available high-protein food source for wildlife, especially for young animals. Following settlement, the sagebrush ecosystem was damaged by livestock overuse and drought. Native grasses and forbs were often replaced by alien plant species of little forage value. Deteriorated range and dry weather patterns favored the increase of grasshoppers to densities that caused severe damage to the ecosystem. Because of the magnitude of these problems and the relatively low-scale economics of sagebrush management, revitalization of degraded areas is a long-term process. Management practices benefiting wildlife and livestock in common include; (1) controlling soil erosion and improving soil moisture infiltration and retention, (2) increasing diversity of perennial plant species and heterogeneity of vegetative cover within small units, (3) managing livestock and big game in a manner that improves or maintains range condition, and (4) utilizing integrated pest management with minimal use of broad-spectrum chemical pesticides. Research needs include; (1) methods of rejuvenating degenerate sagebrush stands, (2) closer definition of the function and value of wild vertebrates in healthy sagebrush ecosystems, (3) techniques for increasing beneficial wildlife, such as placement of nest boxes, and (4) devising effective and economical integrated pest management systems.

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INTRODUCTION

The sagebrush (*Artemisia* spp.) ecosystem is one of the most important habitats for wild vertebrates in the western United States by virtue of its vast area (35-105 million ha; Laycock 1979), heterogeneity of local sites, and relative absence of disturbance. The large geographical area and variety of sites to which sagebrush has adapted indicate coevolution with a spectrum of other plant and animal species (Blaisdell et al. 1982). Sagebrush communities provide key habitat for associated wildlife, although productivity is lower than in more mesic, temperate communities. Interdependence between wild vertebrate species and the sagebrush ecosystem is highly variable, but management objectives and limitations can be clearly defined (Laycock 1979, Young et al. 1979, Rutherford and Snyder 1983).

EVOLUTION OF SAGEBRUSH ECOSYSTEM BIOTA

The evolution of the sagebrush ecosystem provides a perspective for understanding species relationships. Modern grasses, forbs, and large grazing mammals began to flourish in the Miocene, about 25 million years ago (Curry-Lindahl 1981). The sagebrush group (*Tridentatae*) developed in the Pleistocene about 2 million years ago (McArthur and Plummer 1978). In contrast, birds appeared nearly 100 million years ago (Feduccia 1980), modern Orthoptera more than 200 million years ago (Carpenter 1953, Manton 1977), and reptiles and amphibians are even older. Thus, modern sagebrush-grass-forb plant species coevolved with, or through, the primary animal components of the system.

Herbivorous insects and vertebrates have been viewed primarily as exploiters of plants in a one-way relationship. However, an interdependence that we do not fully understand must have evolved between plants and herbivorous animals. For example, some plants may need feeding activity by herbivores to maintain fitness and species attributes, and may require this stimulus for maximum productivity (Harris 1974, Owen 1980, McEwen 1982).

Wild vertebrates contribute to the basic ecological functions. These include energy flow, nutrient cycling, seed dispersal, vegetative cover and succession, interaction with and regulation of invertebrate and other vertebrate populations, maintenance of genetic diversity, and ecosystem stability. However, the significance of some major faunal components, such as bird populations, in ecosystem function is not known (Wiens 1977).

WILDLIFE IN THE SAGEBRUSH ECOSYSTEM

Mammals

Few species of mammals are restricted entirely to sagebrush habitats although the sagebrush vole, the Great Basin pocket mouse, and the pygmy rabbit are considered obligatory (scientific names of vertebrates are listed in Tables 1-3). Many species are partially dependent on sagebrush for food, cover, breeding requirements, winter range,

or other needs. A limited review of the literature reveals that sagebrush provides habitat for 53 species of mammals (Table 1). At least 36 additional species use sagebrush but are less closely associated with it.

Birds

The avifauna associated with sagebrush habitats are richer than might be expected. More than 100 species of birds are known to forage and nest in sagebrush communities (Braun et al. 1976). As with mammals, few bird species are entirely restricted to sagebrush stands. Four species whose breeding territories most frequently include sagebrush in the vegetative cover are sage grouse, sage thrasher-

er, sage sparrow, and Brewer's sparrow. Two species considered near-obligates are the green-tailed towhee and vesper sparrow. Other bird species are also commonly found in sagebrush habitats (Table 2). Overall, breeding bird population

Table 1.--Mammalian species of the sagebrush ecosystem^{1/}

Obligatory Species	
Great Basin pocket mouse	<u>Perognathus parvus</u>
Sagebrush vole	<u>Lagurus curtatus</u>
Pygmy rabbit	<u>Sylvilagus idahoensis</u>
Other species	
Big brown bat	<u>Eptesicus fuscus</u>
Merriam's shrew	<u>Sorex merriami</u>
Desert shrew	<u>Notiosorex crawfordi</u>
Ermine	<u>Mustela erminea</u>
Long-tailed weasel	<u>M. frenata</u>
Black-footed ferret	<u>M. nigripes</u>
Badger	<u>Taxidea taxus</u>
Western spotted skunk	<u>Spilogale gracilis</u>
Striped skunk	<u>Mephitis mephitis</u>
Coyote	<u>Canis latrans</u>
Gray Wolf	<u>C. lupus</u>
Red fox	<u>Vulpes vulpes</u>
Kit fox	<u>V. macrotis</u>
Gray fox	<u>Urocyon cinereoargenteus</u>
Bobcat	<u>Felis rufus</u>
Black-tailed prairie dog	<u>Cynomys ludovicianus</u>
White-tailed prairie dog	<u>C. leucurus</u>
Townsend's ground squirrel	<u>Spermophilus townsendii</u>
Washington ground squirrel	<u>S. washingtoni</u>
Richardson's ground squirrel	<u>S. richardsoni</u>
Thirteen-lined ground squirrel	<u>S. tridecemlineatus</u>
Golden-mantled ground squirrel	<u>S. lateralis</u>
White-tailed antelope squirrel	<u>Ammospermophilus leucurus</u>
Least chipmunk	<u>Tamias minimus</u>
Northern pocket gopher	<u>Thomomys talpoides</u>
Little pocket mouse	<u>Perognathus longimembris</u>
Yellow-eared pocket mouse	<u>P. xanthonotus</u>
Dark kangaroo mouse	<u>Microdipodops megacephalus</u>
Panamint kangaroo rat	<u>Dipodomys panamintinus</u>
Ord's kangaroo rat	<u>D. ordii</u>
Chisel-toothed kangaroo rat	<u>D. microps</u>
Western harvest mouse	<u>Reithrodontomys megalotis</u>
Deer mouse	<u>Peromyscus maniculatus</u>
Canyon mouse	<u>P. crinitus</u>
Northern grasshopper mouse	<u>Onychomys leucogaster</u>
Southern grasshopper mouse	<u>O. torridus</u>
White-throated woodrat	<u>Neotoma albigula</u>
Bushy-tailed woodrat	<u>N. cinerea</u>
Desert woodrat	<u>N. lepida</u>
Long-tailed vole	<u>Microtus longicaudus</u>
Porcupine	<u>Erethizon dorsatum</u>
White-tailed jack rabbit	<u>Lepus townsendii</u>
Black-tailed jack rabbit	<u>L. californicus</u>
Nuttall's cottontail	<u>Sylvilagus nuttallii</u>
Desert cottontail	<u>S. auduboni</u>
Elk	<u>Cervus elaphus</u>
Mule deer	<u>Odocoileus hemionus</u>
Pronghorn	<u>Antilocapra americana</u>
Bison	<u>Bison bison</u>
Mountain sheep	<u>Ovis canadensis</u>

^{1/} Sagebrush is identified in the habitat descriptions for each species in one or more of the following publications: Fautin (1946), Martin et al. (1951), Armstrong (1972), Burt and Grossenheider (1976), and McAdoo and Klebenow (1979). Common and scientific names are after Jones et al. (1982).

Table 2. Avian species of the sagebrush ecosystem^{1/}

Obligatory Species	
Sage grouse	<u>Centrocercus urophasianus</u>
Sage thrasher	<u>Oreoscoptes montanus</u>
Brewer's sparrow	<u>Spizella breweri</u>
Sage sparrow	<u>Amphispiza belli</u>
Near-Obligatory Species	
Green-tailed towhee	<u>Pipilo chlorurus</u>
Vesper sparrow	<u>Poocetes gramineus</u>
Common Species	
Swainson's hawk	<u>Buteo swainsoni</u>
Golden eagle	<u>Aquila chrysaetos</u>
American kestrel	<u>Falco sparverius</u>
Prairie falcon	<u>F. mexicanus</u>
Chukar	<u>Alectoris chukar</u>
Sharp-tailed grouse	<u>Tympanuchus phasianellus</u>
Scaled quail	<u>Callipepla squamata</u>
Mountain quail	<u>Oreortyx pictus</u>
Killdeer	<u>Charadrius vociferus</u>
Mourning dove	<u>Zenaida macroura</u>
Burrowing owl	<u>Athene cunicularia</u>
Common nighthawk	<u>Chordeiles minor</u>
Gray flycatcher	<u>Empidonax wrightii</u>
Ash-throated flycatcher	<u>Myiarchus cinerascens</u>
Western kingbird	<u>Tyrannus verticalis</u>
Horned lark	<u>Eremophila alpestris</u>
Black-billed magpie	<u>Pica pica</u>
Rock wren	<u>Salpinctes obsoletus</u>
Loggerhead shrike	<u>Lanius ludovicianus</u>
Cassin's sparrow	<u>Aimophila cassinii</u>
Lark sparrow	<u>Chondestes grammacus</u>
Black-throated sparrow	<u>Amphispiza bilineata</u>
Lark bunting	<u>Calamospiza melanocorys</u>
Western meadowlark	<u>Sturnella neglecta</u>
Brewer's blackbird	<u>Euphagus cyanocephalus</u>
Brown-headed cowbird	<u>Molothrus ater</u>
Other Species ^{2/}	
Northern harrier	<u>Circus cyaneus</u>
Red-tailed hawk	<u>Buteo jamaicensis</u>
Ferruginous hawk	<u>B. regalis</u>
Lesser prairie-chicken	<u>Tympanuchus pallidicinctus</u>
California quail	<u>Callipepla californica</u>
Upland sandpiper	<u>Bartramia longicauda</u>
Great horned owl	<u>Bubo virginianus</u>
Long-eared owl	<u>Asio otus</u>
Short-eared owl	<u>A. flammeus</u>
Broad-tailed hummingbird	<u>Selasphorus platycercus</u>
Western flycatcher	<u>Empidonax difficilis</u>
Say's phoebe	<u>Sayornis saya</u>
Eastern kingbird	<u>Tyrannus tyrannus</u>
Barn swallow	<u>Hirundo rustica</u>
American crow	<u>Corvus brachyrhynchos</u>
House wren	<u>Troglodytes aedon</u>
Mountain bluebird	<u>Sialia currucoides</u>
Blue-gray gnatcatcher	<u>Polioptila caerulea</u>
Northern mockingbird	<u>Mimus polyglottos</u>
Lazuli bunting	<u>Passerina amoena</u>
Black-chinned sparrow	<u>Spizella atrogularis</u>
Grasshopper sparrow	<u>Ammodramus savannarum</u>
Red-winged blackbird	<u>Agelaius phoeniceus</u>
House finch	<u>Carpodacus mexicanus</u>

^{1/} Derived from Wiens and Dyer (1975), Braun et al. (1977), Chase et al. (1982), American Ornithologists Union (1983), and unpublished data of L.C. McEwen. Scientific and common names follow A.O.U. (1983).

^{2/} A complete list of avian species recorded in sagebrush habitat is available from C.E. Braun, Colorado Division of Wildlife, Fort Collins, CO 80526, or the senior author.

densities are lower than in more complex ecosystems, but greater than in systems dominated by low-growing plants with less height diversity (Johnson et al. 1980).

Reptiles and Amphibians

The herpetofauna of the sagebrush ecosystem (Table 3) are relatively rich. Sagebrush is identified

Table 3.--Reptiles and amphibians of the sagebrush ecosystem^{1/}

Species Commonly Found in Sagebrush	
Tiger salamander	<u>Ambystoma tigrinum</u>
Long-toed salamander	<u>A. macrodactylum</u>
Western spadefoot	<u>Scaphiopus hammondi</u>
Great basin spadefoot	<u>S. intermontanus</u>
Woodhouse's toad	<u>Bufo woodhousei</u>
Great Plains toad	<u>B. cognatus</u>
Collared lizard	<u>Crotaphytus collaris</u>
Leopard blizard	<u>C. wislizenii</u>
Desert spiny lizard	<u>Sceloporus magister</u>
Western fence lizard	<u>S. occidentalis</u>
Sagebrush lizard	<u>S. graciosus</u>
Side-blotched lizard	<u>Uta stansburiana</u>
Tree lizard	<u>Urosaurus ornatus</u>
Desert horned lizard	<u>Phrynosoma platyrhinos</u>
Short-horned lizard	<u>P. douglassi</u>
Great Basin skink	<u>Eumeces skiltonianus</u>
Great Basin Whiptail	<u>Cnemidophorus tigris</u>
Northern alligator lizard	<u>Gerrhonotus coerules</u>
Striped racer	<u>Masticophis lateralis</u>
Striped whipsnake	<u>M. taeniatus</u>
Western patch-nosed snake	<u>Salvadora hexalepis</u>
Glossy snake	<u>Arizona elegans</u>
Great Basin gopher snake	<u>Pituophis melanoleucus</u>
Long-nosed snake	<u>Rhinocheilus lecontei</u>
Western terrestrial garter snake	<u>Thamnophis elegans</u>
Black-necked garter snake	<u>T. cyrtopsis</u>
Western ground snake	<u>Sonora semiannulata</u>
Night snake	<u>Hypsiglena torquata</u>
Western rattlesnake	<u>Crotalus viridis</u>
Other Species Found in Sagebrush	
Western toad	<u>Bufo boreas</u>
Red-spotted toad	<u>B. punctatus</u>
Western box turtle	<u>Terrapene ornata</u>
Banded gecko	<u>Coleonyx variegatus</u>
Lesser earless lizard	<u>Holbrookia maculata</u>
Many-lined skink	<u>Eumeces multivirgatus</u>
Racer	<u>Coluber constrictor</u>
Coachwhip	<u>Masticophis flagellum</u>
Common kingsnake	<u>Lampropeltis getulus</u>
Milk snake	<u>L. triangulum</u>
Western diamondback rattlesnake	<u>Crotalus atrox</u>

^{1/} Derived mainly from Stebbins (1966) and also McAdoo and Klebenow (1979). Scientific and common names follow Stebbins (1966).

in the habitat descriptions of 35 species of reptiles and amphibians by Stebbins (1966) and six additional species are listed in McAdoo and Klebenow (1979). None are completely obligatory except possibly the sagebrush lizard.

SAGEBRUSH ECOSYSTEM DAMAGE AND DESTRUCTION

There are several reports of severe disturbance caused by the animal components of the sagebrush ecosystem. Feeding by grasshoppers (Acrididae), combined with drought, killed 15-50% of the sagebrush over large areas of northeastern Wyoming and southeastern Montana even though sage was not a preferred food for those species (Allred 1941). A moth (Aroga websteri) caused varying degrees of sagebrush defoliation on 4.8 million ha in Oregon in 1962 (Gates 1964). Voles damaged and killed big

sagebrush in Montana, Idaho, Utah, and Nevada (Frischnecht and Baker 1972). Rodents often locally reduce cover and growth of range plants (McAdoo and Klebenow 1979), but rodent activities can ultimately benefit soil condition and forage production (Lasater 1972, p. 55). Burrowing animals improve soil structure, fertility and moisture retention (Grinnell 1923, Sampson 1952). Jack rabbits are serious competitors for forage in dry years, especially when populations are at cyclic highs, but they cause little harm on range in good condition (Taylor et al. 1935). Large herbivores, especially mule deer, can also damage sagebrush ecosystems when winter populations are too high (Rutherford and Synder 1983).

Biological perturbations are transient and do not result in permanent system destruction under natural conditions, but their impacts may be intensified by man. Human interference, deliberate or unintentional, includes poor livestock management causing severe overgrazing (Tisdale et al. 1969), mechanical and chemical destruction of sagebrush, and the introduction of annual plants such as downy brome (Bromus tectorum) and medusahead (Taeniatherum asperum). Introduced annuals can become widespread, dominating and degrading natural communities. This causes difficult management problems in restoring productivity for livestock and wildlife (Young et al. 1979), and ecosystem recovery may take decades.

ECOSYSTEM DIVERSITY

One key to improving sagebrush ecosystem vigor and productivity is to maintain or increase the diversity of its components. Diversity in this sense means a variety and mixture of plant and animal species, vegetative age classes, differing height structure, and horizontal patchiness within relatively small units of the landscape. Greater diversity of plant and animal life in the system provides better forage quality and greater carrying capacity for livestock and wildlife, fewer problems with pest species, and more efficient management. Diversification of habitat must be done in accord with specific management objectives to attain the desired benefits (Thomas et al. 1979).

Early efforts to "eradicate" sagebrush and "improve" rangeland for livestock were directed at increasing grass production (Vale 1974, Wallestad 1975). In recent years, research has shown that cattle and sheep gain faster on mixed diets of forbs and shrubs in addition to grasses (Laycock and Phillips 1968, Pieper and Beck 1980, Holechek and Vavra 1982, Cook 1983, Provenza and Richards 1984). A change in emphasis from "eradicating" to managing sagebrush with the objective of maintaining or creating vigorous mixtures of grasses, forbs, and shrubs meshes, the goals of wildlife and livestock management on range.

Diversity of plant cover (species, height, age-classes, patchiness) creates more niches for more species of wild vertebrates and generally supports higher population densities (Balda 1975, Behle 1978, Hair 1980). Sagebrush is an extremely important winter food for pronghorn (Bayless 1969, Wallmo 1973) and mule deer (McAdoo and Klebenow

1979). However, pronghorn "thrive best on range-lands with a diversity of vegetation, an abundance of grass-forbs-browse..." (Yoakum 1975). Deer will starve on a diet of sagebrush alone, but can utilize up to 50% in their diet in combination with other foods (Rutherford and Snyder 1983). Urness (1979) reported that most species of wildlife do best where stands have good mixtures of shrubs, grasses, and forbs occurring in relatively small areas.

Plant cover diversity is related to range condition; more vigorous, productive range has greater mixtures of species, age-classes, and types of forage, (Tueller 1973, Blaisdell et al. 1982). Sagebrush stands in good condition favor many wildlife species. However, some wildlife species are adapted to lower condition stands and earlier successional stages. These species are more abundant where there is more bare ground, sparse cover, and invader plants. Examples are horned larks, kangaroo rats, and certain ground squirrels.

Breeding bird populations are generally related to heterogeneity of the vegetation. With increases in plant height (structure) from the relatively uniform short-grass plains, to more varied shrub-steppe, to forest stands with mixed species and age classes, there is a corresponding increase in density and species of breeding birds. However, within shrub-steppe communities, breeding bird relationships to variations in structure are not clear (Wiens and Rotenberry 1981). An examination of big sagebrush (*A. tridentata*) and greasewood (*Sarcobatus vermiculatus*) cover in relation to densities of breeding Brewer's sparrows (unpubl. data, L.C. McEwen) revealed that bird density was positively correlated with up to 6% shrub cover, but bird numbers were not correlated at higher percentages (Fig. 1). Wiens and Rotenberry (1981) found that shrub-steppe plant species composition and vegetative cover percentage were as important as plant height for birds.

The value of vegetative cover diversity and "edges" between cover types for wildlife has become a wildlife management principle (Leopold 1948, Gysel and Lyon 1980). Several methods of quantifying "edge" and habitat diversity have been devised (Patton 1975, Thomas et al. 1979, Heinen and Cross 1983). Use of these indexes supports the premise that increasing diversity improves the habitat for many wildlife species. Based on this principle, an open stand of vigorous sagebrush with a diverse understory of forbs and grasses, frequent openings exceeding the shrub cover in area, and mixtures of other shrubs, would support more desirable vertebrate species and higher populations.

INTEGRATED PEST MANAGEMENT

Integrated pest management (IPM) has been defined as using all available tools to suppress pest populations below economic damage levels. These tools include cultural methods, genetic resistance of plants, natural predators, parasites, and diseases, along with prudent use of chemical pesticides. IPM was conceived and developed because of the growing failure of chemical pesticides to control serious

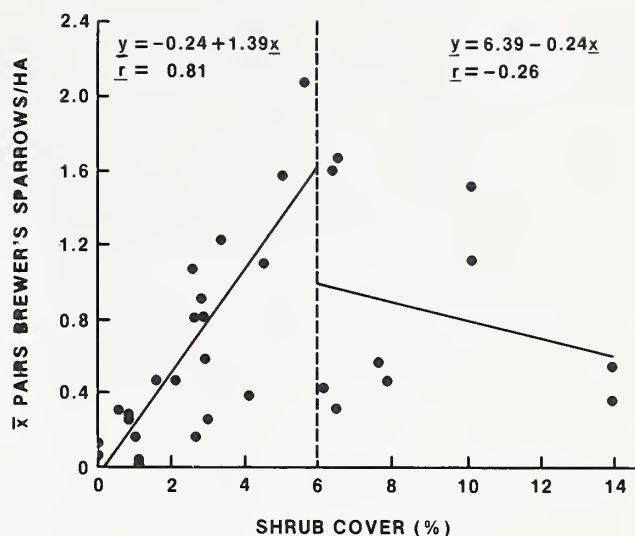


Figure 1.—Density of nesting Brewer's sparrows vs. shrub cover in Big Horn County, Montana.

agricultural and public health pests when used indiscriminantly. Problems arose from the rapid development of resistance to pesticides, the creation of new pests from formerly innocuous species by releasing them from natural controls, toxic effects on non-target life, and widespread environmental contamination with hazardous synthetic chemicals (Metcalf 1980, Turpin and York 1981). IPM methods may be more applicable to intensively managed land than to large areas of rangeland undergoing little direct management. Despite the substantial effort required to apply IPM principles to the sagebrush ecosystem, range managers should consider its implementation. Natural controls of pest species should be identified and encouraged. Cultural objectives could include increasing plant species diversity and heterogeneity of cover types. This would improve microhabitats for natural enemies of pests and help avoid the pest problems created by monotypes (Haws 1982); also, habitat for vertebrate predators would be enhanced.

An example is the Pawnee National Grassland in Colorado. This land was abandoned by landowners in the 1930's because of soil erosion, low productivity and grasshopper plagues. Good grazing management by the Soil Conservation Service and later by the U.S. Forest Service has restored a vigorous shortgrass ecosystem with a full complement of wild vertebrates. Although several extensive grasshopper spray projects have been conducted on nearby rangeland under other ownership, no grasshopper control has been necessary on the Pawnee for many years.

The effectiveness of wild vertebrates as regulators of insect pest populations is not fully known. There are several reports of significant reduction of pests by birds (McFarlane 1976, DeGraaf 1978). The consensus is that bird predation can prevent buildups to epidemic stages when pest populations

are low, but birds are not believed effective in controlling widespread outbreaks after they have developed (Otvos 1979).

Wiens and Dyer (1975) estimated that insect and invertebrate prey comprised 80% of the food biomass consumed by breeding rangeland birds. For nearly all rangeland species (excepting mourning doves and large raptors), food of young growing birds approaches 100% animal material, mainly insects. Wiens (1977) and others regard the role of birds in rangeland ecosystems as unclear and suggest that bird populations may be functionally insignificant. In contrast, recent work by Joern (1984) has shown that bird predation can be a significant regulator of grasshopper populations. Continuing experimentation and study should clarify the function of birds in rangeland ecosystems. For example, we found that fewer grasshoppers were present where bird densities were higher on mixed sagebrush range in southeastern Montana (Fig. 2, unpubl. data, L.C. McEwen). More investigation of bird/pest insect relationships on rangelands is needed.

A strong case exists for biological control of forest insect pests (and elimination of chemical pesticides) by utilizing birds that prey on pests (Takekawa et al. 1982). In some European countries, forest insect pests have been effectively suppressed by birds for many years. Forest management there encourages beneficial birds, mostly by large-scale strategic placement of nest boxes. Up to several hundred thousand boxes are placed in management units (Takekawa et al. 1982). While such efforts may not be practical on all rangeland, nest boxes will attract highly insectivorous species such as bluebirds, wrens, and the American kestrel, and might be effective in some situations. If this method proved efficient in chronic grasshopper problem areas, it could be less costly than spraying insecticides every few years. The potential for increasing birds by placing nest boxes on sagebrush range would be lower than in forest habitats where there are more hole-nesting species, but it can be successful. American kestrels were attracted to previously

unoccupied sagebrush-juniper habitat in California by placing 52 nest boxes. The boxes had a mean annual use rate of 31% the first four years (Bloom and Hawks 1983). Numbers of kestrels using the boxes were highest the fourth year. Seven other insectivorous bird species were observed nesting in one or more boxes. Nest boxes that were erected in sagebrush-steppe and mixed grass rangeland in Montana and Wyoming attracted mean annual use of 80% by kestrels (Palmer et al. 1982). Developing methods of increasing beneficial wild vertebrates as a pest control measure in the sagebrush ecosystem is a fertile field for research.

Biological control methods offer promise for regulating short-horned grasshoppers (Acrididae) and Mormon crickets (Tettigoniidae or long-horned grasshoppers) in the sagebrush ecosystem. Although grasshoppers are known to feed mainly on grasses and forbs, Sheldon and Rogers (1978) found that 7 of 8 species studied selected big sagebrush as a preferred food. The microsporidian *Nosema locustae* is a natural grasshopper pathogen used as a biological population regulator. Spores of *Nosema* can be cultured and produced in quantities, mixed with bran, and spread by air much like a chemical formulation and at comparable cost (Henry et al. 1978). Infection of grasshoppers is slow following spread of *Nosema* spores (in contrast to a quick chemical knockdown), thus, more forage is damaged or lost before grasshopper numbers are reduced to non-economic levels. A possible advantage of *Nosema* use is the potential to reinfest grasshoppers from year to year and provide long-term control without further effort or cost. In two separate field experiments in cooperation with the U.S. Department of Agriculture Rangeland Insect Laboratory, *Nosema* applied to rangeland had no adverse impact on wild vertebrates in the treated areas (McEwen 1982). Pest control with target-specific pathogens is ideal for preventing non-target effects and maintaining ecosystem stability. Use of biological pest control methods should be expanded, and reliance on broad-spectrum chemicals reduced. However, chemical pesticides that degrade rapidly and are low in toxicity to wild vertebrates have a definite place in IPM on rangeland. Efficiency of insecticide use can be improved (Onsager 1984).

SAGEBRUSH MANAGEMENT RECOMMENDATIONS

Extensive sagebrush type-conversion and renovation projects throughout the west have caused management agencies great concern over wildlife habitat degradation and loss (Wallestad 1975). Much research has been done on effects of sagebrush control on wildlife populations, and on development of control methods that reduce adverse impacts. Studies of breeding bird populations have shown the reduction or disappearance of some species after spraying (Feist 1968, Best 1972, Schroeder and Sturges 1975, Castrale 1982). An investigation by Kufeld (1968) found that 19 of 22 sagebrush control projects in Colorado were detrimental to mule deer and none was beneficial; of 12 sagebrush spray projects on elk range, 4 were detrimental and 3

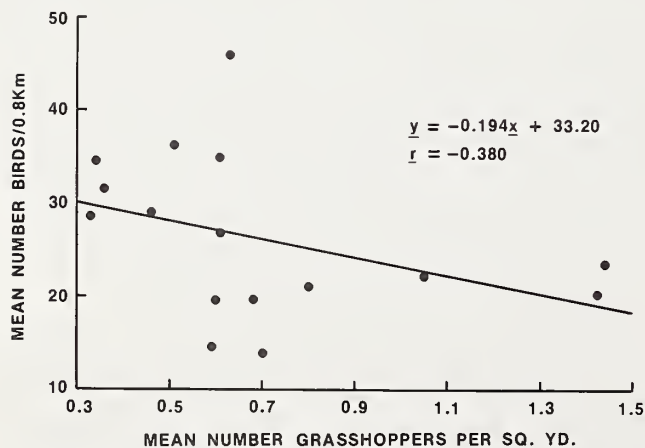


Figure 2.--Relationship of bird numbers to grasshopper densities in July on rangeland, Big Horn County, Montana.

beneficial; of 13 projects in sage grouse habitat, all were detrimental. Kufeld (1968) recommended a 5-step "System for Evaluation and Exchange of Information on Range Type-Conversion Projects." The plan, providing for cooperation and coordination between public land management agencies and the Colorado Division of Wildlife, was adopted in 1968.

Concern about the effects of sagebrush removal on associated birds and other wildlife prompted six recommendations from conservation groups and wildlife agencies (Braun et al. 1976, Braun et al. 1977, Autenreith et al. 1982). The recommendations to make sagebrush control practices more compatible with wildlife habitat needs included: (1) do not control sagebrush cover where it is <20% or on steep slopes (>20% gradient) with shallow soils, (2) sagebrush removal should be done in irregular strips ca. 100 m wide and 16 ha in area leaving untreated strips of greater width, (3) removal strips should be perpendicular to prevailing winds and slopes, (4) 100-m wide strips of live sagebrush should be retained on edges and drainages, (5) key wildlife winter-use habitat should be avoided altogether, and (6) control should be done before late April or after mid-July to reduce effects on nesting birds.

Rutherford and Snyder (1983) give a detailed discussion of sagebrush alteration and big game and sage grouse habitat. They recommended, "Any manipulation that will improve the multiple-species composition of browse plants, and the maintenance of grass-forb understory, on sagebrush winter range is to be seriously considered." For big game habitat in particular, they recommended converting pure sagebrush stands to mixed browse range, within site limitations.

Herbicide application is one of the primary methods for reducing or eliminating sagebrush on rangeland (Evans et al. 1979). Herbicides generally are less acutely toxic than other types of pesticides, but they are not without risk. The common phenoxy herbicides 2,4-D and 2,4,5-T are moderately carcinogenic (Hay 1982, Reuber 1983). The latter may contain toxic and teratogenic dioxin impurities (Allen et al. 1979, Hay 1982), although concentrations have been reduced by improved manufacturing processes. Some herbicides are toxic to bird embryos, and effects are magnified in an oil formulation (Hoffman and Albers 1984). Oil alone is toxic to eggs (Kopischke 1972), and as little as 10 µl can be lethal to an embryo at its most sensitive stage. This could be important if an oil formulation of a herbicide were applied during the nesting season. More desirable alternatives to herbicides are mechanical control in small patches or, under certain conditions, by carefully done light burning. The latter methods are less costly and less disruptive to the ecosystem in the long term when properly applied. Many arthropod species are associated with broad-leaved plants, thus brush and forb herbicides indirectly reduce insects which are the essential source of animal protein for young birds (Putnam 1949, Potts 1977, Warner 1984).

A common management practice has been to seed areas with crested wheatgrass (*Agropyron cristatum*) where sagebrush has been removed. Crested wheatgrass is a valuable spring forage for big game, but the ecosystem changes are largely negative if the seeded blocks are too large. Reynolds and Trost (1980) studied crested wheatgrass stands on former sagebrush range and found significant losses of diversity and numbers of small mammals, birds, and reptiles. Breeding birds were reduced to only one species - horned larks. Wildlife derive much greater benefit from seeding mixtures of grasses, forbs, and shrubs on sagebrush removal sites as recommended by Stevens et al. (1981), Holechek and Stephenson (1983), and Provenza and Richards (1984).

Livestock grazing management holds promise for improving wildlife habitat (Urness 1979). Frischnecht (1979) cited several studies showing grass and forb increases following fall grazing of sagebrush by domestic sheep. Livestock effects on big game habitat under different stocking rates, length of grazing period, and season of use were reviewed by Severson and Medina (1983). They reported a potential for upgrading habitat, but a need for further research.

SAGEBRUSH MANAGEMENT GOALS AND RESEARCH NEEDS

Sagebrush management that would benefit most wildlife species, livestock, and the entire ecosystem should include at least 4 goals.

1. Prevent soil erosion, improve soil structure, increase fertility, and improve moisture infiltration and retention.
2. If the vegetation is manipulated, the goal should be to increase vigor, growth, species diversity, and heterogeneity of cover and height within small units.
3. Manage livestock and big game populations to prevent overuse and to improve or maintain good range condition and wildlife habitat.
4. Practice preventive pest control, use integrated pest management, and minimize use of chemical pesticides.

Research needs range from acquiring basic knowledge to developing applied methodology. We suggest the following as important needs:

1. Develop effective and economical methods of diversifying and improving the condition of extensive stands of sagebrush, especially areas invaded by downy brome, medusahead, or other exotic annuals.
2. Develop methods for enhancing habitat and attracting beneficial birds and other wildlife to suppress pest populations below economic damage densities.
3. Determine the function of wild vertebrate species in the sagebrush ecosystem and their interactions with other components.

4. Select and develop cultivars of hardy, tolerant, nutritious and productive grasses, forbs, and shrubs for revegetating sites where sagebrush has been removed.

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